US Army Corps of Engineers

U.S. Army Corps of Engineers
Walla Walla District

Lower Snake River Programmatic Sediment Management Plan

Draft Environmental Impact Statement

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Lower Snake River Draft Programmatic Sediment Management Plan Environmental Impact Statement

Appendix A: Draft Programmatic Sediment Management Plan

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SECTION 1.0 INTRODUCTION

1.1 Purpose of the Programmatic Sediment Management Plan

The Programmatic Sediment Management Plan (PSMP) guides all U.S. Army Corps of Engineers (Corps), Walla Walla District, sediment management activities. It provides a programmatic framework to manage and prevent, if possible, the accumulation of sediment to meet authorized purposes of commercial navigation, hydroelectric power generation, recreation, and fish and wildlife conservation.

The PSMP is a long-term plan that forms the basis of the sediment management system for the four lower Snake River dams (along with their associated locks and reservoirs), hereafter referred to as the Lower Snake River Projects (LSRP). In this regard, the PSMP is like a roadmap to inform the decision-making process of future sediment management activities. The PSMP is intended to be a living document, functioning as an "adaptive management plan." Adaptive management is a systematic process developed in order to continually improve management policies and practices by learning from the results of implemented measures.

It is equally important to note those things the PSMP is not intended to do. First, it does not prescribe project-specific solutions. Rather, it provides a menu of potential measures that may be applicable for sediment accumulation issues. To facilitate the Corps' selection of measures to effectively address problems in the least costly, an environmentally acceptable manner, consistent with engineering requirements it provides a framework for assessing problems and potential solutions, selecting solutions, monitoring and, ultimately, changing practices based on monitoring and evaluation. Further, the PSMP guides only those actions taken by the Corps within the project boundaries of the LSRP. The PSMP does not apply to actions taken by other organizations or agencies outside of the LSRP boundaries.

When implementing emergency actions, the Corps is exempt from the National Environmental Policy Act (NEPA) process laid out in the PSMP. Per 33 Code of Federal Regulations (CFR) 230.8, emergency procedures apply when the Corps determines it is necessary to declare an emergency condition requiring sediment management to prevent or reduce imminent hazard to human life, health, or property, or due to severe economic losses posed by the conditions. In lieu of the environmental review process contained within this plan, the District Commander would be responsible for considering the probable environmental consequences resulting from the proposed action, and determine the appropriate documentation.

1.2 Corps Authorities, Directives, and Obligations

In response to Congressional authorization, the Corps has constructed and operates and maintains the navigation system on the lower Snake River, which is part of an inland navigation system from Lewiston, Idaho to the Pacific Ocean and includes a portion of the Columbia River. Congress authorized the reservoir system and the navigation channel that runs through the reservoirs by the River and Harbor Act of 1945 (Public Law [PL] 79-14), Section 2. This Act included authorization for the construction of the Ice Harbor, Lower Monumental, Little Goose, and Lower Granite lock and dams for the purposes of inland navigation, power generation, and incidental irrigation water supply. The Flood Control Act of 1944 (PL 78-534) authorized the Chief of Engineers to construct, maintain, and operate recreational facilities in reservoir areas under Corps management. Compliance with the Fish and Wildlife Coordination Act of 1958 (PL 85-624) resulted in certain modifications to the LSRP during and after construction for fish and wildlife conservation/mitigation and added the same as an authorized project purpose.

The Flood Control Act of 1962 (PL 87-874) mandated the establishment of the navigation channel within the LSRP at 14 feet deep by 250 feet wide at the minimum operating pool level, and provides the Corps with authority to maintain the channel at those dimensions. Based on the authorizing documents and subsequent related Congressional documents, the Corps interprets that Congress intended for the Corps to maintain the channel to provide year-round navigation. In 1991, Congress reiterated its intent to provide for navigation in the Columbia and Snake River system (102 Senate Report 80). The designated Federal navigation channel dimensions are increased beyond typical dimensions in the turning basins in front of port berthing areas in accordance with navigation practice as authorized in the United States Code (U.S.C.) at 33 U.S.C. § 562: "Channel dimensions specified shall be understood to admit of such increase at the entrances, bends, sidings, and turning places as may be necessary to allow of the free movement of boats."

The LSRP provide aquatic and shoreline recreational opportunities. There are 51 designated recreation sites located on the shores and adjacent areas of the Snake River between the confluence with the Columbia River and the upstream end of the Lower Granite Reservoir on the Snake River. These facilities include local and state parks, and marinas, which are managed and operated by the Corps and local and state recreation agencies.

The original enabling legislation for the Lower Granite Lock and Dam project included construction and maintenance of levees as ***appurtenant*** facilities of the project. This means that the levees provide for normal operating reservoir water levels from 733 to 738 feet above mean sea level in Lewiston – permitting commercial navigation without inundating portions of Lewiston. The levees were originally designed to have a 5-foot ***freeboard*** during the "***standard project flood***," or SPF. This means that the top of the levee would be 5 feet higher than the water level during the SPF. The SPF is a *very* high stream flow resulting from severe meteorological events, specifically a flow of 420,000 cubic feet of water per second in the Snake River downstream of the confluence with the Clearwater River, which is substantially higher than any flows previously recorded. Freeboard was added to the levees to reduce the likelihood of flooding in Lewiston either by very high stream flow or by variable operation of the dam. Since the dam and levees were constructed, the Corps has adopted risk-based methodology to assess the level of flood risk reduction provided by its facilities. The SPF and original design freeboard is no longer the only criterion used to evaluate the risk of flooding.

Design of the levees was consistent with applicable required standards at the time of the construction of the Lower Granite Project. Subsequently Engineer Regulation (ER) 1105-2-101 *Risk Analysis for Flood Damage Reduction Studies* (January 2006) provides guidance on analyzing risks of potential flooding associated with facilities like the Lewiston levee system. ER 1105-2-101 provides a revision to the design standard that required 5 feet of freeboard when passing the SPF, and directs the Corps to use risk analysis to determine the appropriate project approach.

An important constraint currently affecting the Federal navigation channel is Reasonable and Prudent Alternative (RPA) Action 5 in the 2008/2010 Federal Columbia River Power System Biological Opinion (2008/2010 BiOp). This RPA states that the lower Snake River reservoirs will be operated within 1 foot of MOP from April through August each year to help move threatened and endangered juvenile salmonids through the river system to the ocean. Operating the reservoirs at MOP versus full pool (a drop in elevation of 3 to 5 feet) is thought to decrease the amount of time downstream migrating juvenile fish spend in the reservoirs, thereby increasing their overall survival rates. Over time, sediment deposition in the navigation channel reduces the water depth to less than 14 feet deep at MOP, which interferes with navigation. The reservoir level may be adjusted (i.e. raised) to meet authorized project purposes, primarily navigation, per RPA 5, but this deviation from MOP operation is not desirable. Regional fish managers and the Corps view it as a temporary measure for addressing sediment deposition in the navigation channel until maintenance can be performed.

1.3 Corps Sediment Management Guidance

The Corps' ER 1105-2-100, *Planning Guidance Notebook*, provides policies and guidelines for sediment management planning. It directs the Corps to perform dredged material management planning for all Federal harbor projects. The purpose of the planning is to "ensure that maintenance dredging activities are performed in an environmentally acceptable manner, use sound engineering techniques, [and] are economically warranted…." Further, the ER directs incorporation of a "watershed perspective" in conducting civil works planning, which includes accounting for "…the interconnectedness of water and land resources…." While the general guidance contained in the ER was applied in the development of this PSMP and Environmental Impact Statement (EIS), it should be noted that the PSMP EIS was developed to fulfill the requirement of a settlement agreement and provide a long-term plan for operations and maintenance. It is, therefore, different from the typical Corps planning process.

The Corps' Policy Guidance Letter #61 – *Application of Watershed Perspective to Corps of Engineers Civil Works Programs and Activities* (USACE 1999a) provides policy direction to integrate a watershed perspective, including soliciting participation from the spectrum of agencies, tribes, and stakeholders with interests in the Corps' Civil Works programs and involving diverse technical experts. This policy is embodied in the principles of Regional Sediment Management, which stress a "system based approach" to solve sediment-related problems [US Environmental Protection Agency (EPA) 2011, USACE 2011b].

The Sediment Evaluation Framework for the Pacific Northwest (SEF) (USACE 2009) provides guidance for assessing and characterizing sediments in Idaho, Oregon, and Washington. It was developed collaboratively by agencies with responsibility for sediment evaluation and management. The SEF describes methods available for sediment characterizations related to management activities. While the SEF is geared toward determining the suitability of sediments for open water disposal, it also provides consistency for testing and evaluation procedures for sediment management projects in the LSRP.

The Corps' Environmental Operating Principles provide guidance for sediment management planning and all other Corps activities. By following these principles, the Corps aims to develop the scientific, economic, and sociological measures to judge the effects of its projects on the environment and seek better ways to achieve environmentally-sustainable solutions.

1.4 A Watershed Approach

The Corps has historically managed sediment through a program based primarily on dredging. Dredging is cost-effective, proven technology for sediment management, and provides immediate benefit. However, dredging also disturbs the river bottom, which has the potential to adversely affect water quality, cultural resources, aquatic habitat, and aquatic organisms. Dredging addresses the immediate need to remove sediment deposits. It does not, however, address sediment sources or future sediment deposition or provide long-lasting benefits.

Through the PSMP EIS process, the Corps has undertaken a comprehensive watershed-based approach to investigate and analyze sources of sediment from within the sediment-contributing area, how sediment moves through the tributaries, and how sediment moves and is deposited within the lower Snake River reservoirs. This approach was based on public and stakeholder input gathered during scoping meetings (in 2006 and 2007), as well as through extensive coordination and partnering with resource agencies and technical experts with the knowledge and tools to aid in the understanding of sediment yield and transport in the lower Snake River watershed. The purposes of the study were to gain a better understanding of sediment sources and their relative contributions to sediment in the LSRP; and assess opportunities for controlling sediment sources, sediment transport, and sediment deposition as alternative methods to dredging for managing sediments. As part of this effort, the Corps conducted or sponsored intensive data collection and analysis of sediment yields and transport throughout the Snake River Basin. This PSMP EIS incorporates the findings of this data collection and analysis, along with stakeholder input, to identify a range of alternatives for meeting the stated purpose and need.

The Corps manages only a small portion (less than 1 percent) of the more than 32,000 square miles in the lower Snake River's sediment-contributing drainage area. Other branches of the Federal government control most of the drainage area, with 27 percent in Federal wilderness and another 35 percent as national forest (non-wilderness). Private ownership accounts for the final 34 percent of the drainage area.

Other agencies are involved in the management of sediment through land use management practices on surrounding lands, soil conservation practices that limit erosion, and pollutant control programs that indirectly target sediment reduction. The U.S. Forest Service (USFS) owns and manages about 56 percent of the land within the drainage area. Soil erosion results from disturbances on USFS lands, especially from post-wildfire conditions, landslides, and roads in forest areas. The USFS uses various structural and conservation measures to limit soil erosion, including road maintenance and removal, post-fire land treatments, stabilizing and improving channel stability, and protecting and restoring riparian areas.

In agricultural areas (approximately 23 percent of the drainage area), Conservation Districts and other agencies are involved in managing soil resources. Conservation Districts work directly with agricultural users to implement soil conservation practices that limit the soil erosion caused by agricultural practices. In addition, the Idaho Department of Environmental Quality (IDEQ), Oregon Department of Environmental Quality (ODEQ), and the Washington State Department of Ecology (Ecology) address water-borne sediment primarily through their total maximum daily load (TMDL) water quality management plans. All three agencies implement a TMDL planning process, as required by the Clean Water Act (CWA), to develop strategies for the reduction of pollutants in water bodies that do not meet water quality standards. Sediment reduction is often targeted as a means to reduce other pollutants from entering streams. Some plans may also directly address sediment.

As a result of the watershed approach and regional collaboration, the Corps developed a "toolbox" of potentially effective measures they may use to manage sedimentation and maintain the authorized purposes of the LSRP. These measures will be implemented on a site-specific basis, as applicable, and monitored for effectiveness. The Corps will continue to coordinate with other agencies to share information (measures implemented and their effectiveness) in order to expand knowledge regarding sediment migration within the drainage area and refine measures and sediment management as appropriate.

1.5 Relationship to the PSMP EIS

Per NEPA, all Federal agencies are required to consider impacts to the environment from agency actions. In order to comply with NEPA requirements, an EIS was prepared for the PSMP. The Record of Decision (ROD) dated *month, xx, 20xx*, prepared for the EIS documented the purpose and need for the study, EIS alternatives (including selected measures), environmental effects, the decision analysis process, and the selected plan alternative. The ROD also included a summary of the implementation, mitigation, and monitoring plans as appropriate. *The ROD has not been written at the time this draft PSMP was published. It will be prepared after publication of the PSMP Final EIS.*

The PSMP EIS process utilized a comprehensive, watershed-based approach to better understand the contributions of sediment from the watersheds and tributaries that flow into the LSRP. From 2006 through the present, the Corps has conducted or sponsored intensive data collection and analysis of sediment yields and transport throughout the Snake River Basin. The Corps also conducted outreach and coordinated with state and Federal agencies involved in land and water resource management to identify and evaluate methods for managing sediments that affect the authorized purposes of the LSRP. The PSMP EIS incorporated the findings of this outreach, analysis, and coordination to identify and evaluate the appropriate measures to integrate into the PSMP.

The PSMP EIS is a programmatic EIS that evaluated plan alternatives and identified the future course of action in broad, general terms. Plan alternatives are composed of multiple measures, or general types of actions, that could be taken to help the Corps address sediment accumulation that has interfered with the authorized purposes of the LSRP. In accordance with the Council on Environmental Quality (CEQ) regulations implementing NEPA, future project-specific actions will require environmental reviews that build on the general information provided in the programmatic EIS, to the maximum extent practical. This subsequent environmental review process is referred to as “tiering.”

The PSMP is intended to serve as a decision-making tool in determining measures to be applied at a specific location once the need for action has been identified. Individual sediment management projects implemented through the PSMP will comply with all NEPA requirements, including preparation of a tiered environmental assessment (EA) or EIS, and will include opportunities for public and agency comment. The tiered analysis will concentrate solely on site-specific information relevant to specific measures to be implemented.

The project-specific environmental analyses conducted for the NEPA document will provide an essential source of information for PSMP implementation and on-going post-implementation monitoring. As project analyses are completed, new or emerging public issues or management concerns may be identified. In addition, the management measures designed to achieve the project-specific goals are tested for effectiveness through the project analyses. As measures are implemented, post-implementation monitoring will help determine where changes should be made in the PSMP.

1.6 The Local Sediment Management Group’s Role in Long-Term Implementation

The Corps established the Local Sediment Management Group (LSMG) in July 2000 as part of the dredged material management plan (DMMP) process. The LSMG is an information exchange forum comprised of the Corps and Federal and state regulatory agencies, tribal governments, local governments, and non-governmental organizations (e.g., barge operators, Ports, Pacific Northwest Waterways Association). The Corps reconvened the group in 2006 to conduct scoping for the PSMP. The group met throughout the EIS preparation process, providing input to the Corps on sediment management within the LSRP and sharing information with member agencies and stakeholders. The LSMG will continue to play an active role in providing data and suggested updates for the PSMP, and will include:

- Meet at least once each year to review progress and exchange information on sediment management.
- Facilitate interagency communication and coordination regarding sediment management in the lower Snake River Basin.
- Provide a forum to address regional sediment issues regarding the lower Snake River drainage area.

More information regarding Corps interaction with the LSMG is provided in Section 4.

1.7 The PSMP Structure

The PSMP is composed of four primary sections and two attachments:

- *Section 1 - Introduction* provides the user with the purpose of the PSMP, Corps' authority to implement the measures within the PSMP, explanation of the watershed approach, relationship to the programmatic EIS, and the LSMG role in long-term implementation of the PSMP.
- *Section 2 - Sediment Management* includes identification of anticipated problem areas, how the Corps has historically addressed problem areas, and PSMP management measures developed through the EIS process.
- *Section 3 - The PSMP Implementation* provides guidelines for determining the need for action, describes plan formulation and the implementation process, and provides information regarding post-implementation monitoring requirements and adaptive management of the PMSP.
- *Section 4 - Reporting and Updates* sets protocols for reporting results from the implementation of site-specific measures, expectations for coordination with other stakeholders, and timeframe for updating the plan.
- *Attachment A - Implementation Process Summary* provides an abbreviated look at each step in the implementation process, the activities and outcomes associated with each step, and the documentation required for each step.
- *Attachment B - Alternative Measures Preliminary Screening* contains a worksheet to evaluate measures considered for project-specific implementation.

SECTION 2.0 LOWER SNAKE RIVER SEDIMENT MANAGEMENT

2.1 Addressing Maintenance Needs

Based on historic data of sediment accumulation and dredging actions, as well as natural on-going sediment transport, it is clear that sediment accumulation will continue to be a maintenance issue within the LSRP. Research conducted in association with development of the PSMP EIS indicates land management practices within the watershed are effective in improving environmental conditions at a localized level. However, the studies indicated that these measures would not reduce sediments entering the LSRP to the extent sediment accumulation interfering with authorized purposes of the LSRP would be measurably reduced. Therefore, the Corps must continue to address maintenance needs associated with sediment accumulation within the LSRP, as required by statutes and Corps regulations.

The accumulation of sediment in some locations in the LSRP adversely affects the authorized purposes of the Corps' projects, including commercial navigation, fish and wildlife conservation, and recreation. The Corps manages those sediments pursuant to the authorities described in Section 1.2 above, and has historically managed sediments to maintain:

- The Federal navigation channel at the authorized depth of 14 feet deep and 250 feet wide
- The port approaches at 14 feet deep
- Access and use of recreation facilities
- Functioning irrigation water intakes for irrigated habitat management units (HMUs)
- Flow conveyance through the Lewiston levee system consistent with ER 1105-2-101

2.2 Sediment Accumulation Problem Areas

The Corps has identified 43 locations in the reservoirs of Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams where sediment accumulation has historically affected authorized purposes and/or sediment accumulation may potentially be a problem in the future. Table 2-1 identifies these areas, their authorized purpose(s), and their approximate river mile location. Of the locations identified, 21 sites are used for recreation, 16 are navigation sites[1], and 5 sites are related to water intakes. Flow conveyance (as it relates to flood risk management through the Lewiston levee system) and navigation are affected uses at the Snake/Clearwater confluence.

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[1] Several of these sites are port facilities. While the Corps is not specifically authorized to maintain theses sites, the Corps has, at the request of ports, dredged accumulated sediments at these locations to coincide with dredging to maintain the Federal channel. The ports pay the Corps for the dredging and a portion of the administrative costs.

Table 2-1. Potential Sedimentation Problem Areas

Reservoir	River	Approx. River Mile[1]	Site Name	Purpose
Lower Granite	Clearwater	1.0-2.0	Port of Lewiston	Navigation
		3.0	Clearwater Boat Ramp	Recreation
	Snake/ Clearwater	131.5-139.5/ 0.0-2.0	Snake River at Mouth of Clearwater River	Navigation, conveyance
	Snake	128-130	Silcot Island	Navigation
		137.0	Hells Canyon Resort	Recreation
		139.0	Port of Clarkston	Navigation
		139.5	Greenbelt Boat Basin	Recreation
		140.5	Southway Boat Ramp	Recreation
		141.5	Swallows Park Boat Basin and Swim Beach	Recreation
		142.5	Hells Gate State Park	Recreation
		146.0	Chief Looking Glass Park	Recreation
Little Goose	Snake	82.5	Central Ferry Park	Recreation
		83.0	Port of Garfield Access	Navigation
		83.5	Port of Central Ferry	Navigation
		88.0	Willow Landing HMU	Fish and wildlife
		100.0-102.0	Navigation Channel at Schultz Bar	Navigation
		103.5	Port of Almota	Navigation
		103.5	Illia Landing	Recreation
		105.5	Boyer Park and Marina	recreation
		107.0	Lower Granite Lock Approach	Navigation
Lower Monumental	Snake	48.0	Skookum HMU	Fish and wildlife
		51.0	Ayer	Recreation
		55.0	55-Mile HMU	Fish and wildlife
		56.5	Joso HMU	Navigation
		59.5	Lyons Ferry Park	Recreation
		66.0	Texas Rapids Boat Basin	Recreation
		70.0	Little Goose Lock Approach	Navigation
Ice Harbor	Snake	10.0	North Shore Boat Ramp	Recreation
		11.5	Charbonneau Park	Recreation
		13.5	Levey Park	Recreation
		15.0	Big Flat Habitat Management Unit (HMU)	Fish and wildlife
		18.0	Fishhook Park	Recreation
		23.0	Lost Island HMU	Fish and wildlife
		24.5	Hollebeke HMU	Fish and wildlife
		29.0–33.3	Walker's Elevator	Navigation

Table 2-1. Potential Sedimentation Problem Areas

Reservoir	River	Approx. River Mile[1]	Site Name	Purpose
		39.0	Windust Boat Ramp	Recreation
		41.0	Lower Monumental Lock Approach	Navigation
McNary	Snake	0.0	Sacajawea State Park	Recreation
		1.5	Hood Park Boat Ramp	Recreation
		9.2	Ice Harbor Lock Approach/Nav Coffer Cells	Navigation
		0.0–1.5	Snake River Entrance	Navigation
		2.0–10.0	Nav Channel Below Ice Harbor	Navigation

[1] "River Mile" indicates the number of miles upstream of the mouth of the Snake River at its confluence with the Columbia River.

2.3 Historical Sediment Management Activities

The Corps has used periodic dredging to manage sediment as part of operating and maintaining the federal navigation channel. Initially, the Corps has dredged the accumulated sediment from problem areas and disposed of the material either upland or in the reservoirs (called "in-water disposal"). More recently, the Corps has beneficially used dredged sediments to create resting and rearing habitat for juvenile salmon and steelhead listed as threatened or endangered under the Endangered Species Act (ESA). Table 2-2 details the Corps' past dredging actions, most of which were conducted to maintain navigation or flow capacity. The Corps has dredged problem sediment areas approximately every 3 to 5 years, scheduling this dredging when river survey data indicated the sediment deposition was interfering with navigation or other uses of the reservoirs.

Approximately 80 percent of the volume of material historically dredged from the LSRP system has come from Lower Granite Reservoir. Based on recent studies and historic data, it is anticipated that the majority of sediment management activities will continue to occur within Lower Granite Reservoir.

Table 2-2: Partial History of Federal/Port Dredging in the Lower Snake River

Dredging Location	Year	Purpose	Amount Dredged (cubic yards)	Disposal Method
Navigation Channel Ice Harbor, Part I and II, Channel Construction	1961	Navigation	3,309,500	Upland and in-water
Navigation Channel, Ice Harbor Part III, Channel Construction	1962	Navigation	120,000	Upland and in-water
Downstream Navigation Channel, Ice Harbor	1972	Navigation	80,000	Upland and in-water
Downstream Approach, Navigation Channel, Lower Monumental	1972	Navigation	25,000	Upland
Navigation Channel Downstream of Ice Harbor	1973	Navigation	185,000	Upland and in-water
Downstream Approach Channel Const., Lower Monumental Lock	1973	Navigation	10,000	Upland
Downstream Approach Channel Construction, Ice Harbor Lock	1978	Navigation	110,000	Upland and in-water
Downstream Approach Channel Construction, Ice Harbor Lock	1978 1981/82	Navigation	816,814	Upland and in-water
Various Boat Basins, Swallows Swim Beach, Lower Granite Reservoir (Corps)	1975-1998	Recreation	20,000	Upland sites
Port of Lewiston – Lower Granite Reservoir (Corps)	1982	Navigation/Maintain Flow Conveyance Capacity	256,175	Upland sites
Port of Clarkston – Lower Granite Reservoir (Corps)	1982	Navigation	5,000	Upland sites
Downstream Approach Channel Construction, Ice Harbor Lock	1985	Navigation	98,826	In-water
Confluence of Clearwater and Snake Rivers (Corps)	1985	Maintain Flow Conveyance Capacity	771,002	Upland site
Port of Lewiston – Lower Granite Reservoir (Corps)	1986	Navigation/Maintain Flow Conveyance Capacity	378,000	Upland sites
Confluence of Clearwater and Snake Rivers (Corps)	1988	Maintain Flow Conveyance Capacity	915,970	In-water
Confluence of Clearwater and Snake Rivers (Corps)	1989	Maintain Flow Conveyance Capacity	993,445	In-water

Dredging Location	Year	Purpose	Amount Dredged (cubic yards)	Disposal Method
Schultz Bar – Little Goose (Corps)	1991	Navigation	27,335	Upland site
Confluence of Clearwater and Snake Rivers (Corps)	1992	Maintain Flow Conveyance Capacity	520,695	In-water
Barge Approach Lane, Juvenile Fish Facilities, Lower Monumental	1992	Navigation	10,800	Upland site
Ports of Lewiston (Lower Granite Reservoir), Almota & Walla Walla	1991/92	Navigation	90,741	Upland and in-water
Schultz Bar – Little Goose (Corps)	1995	Navigation	14,100	In-water
Confluence of Clearwater and Snake Rivers (Corps)	1996/97	Navigation	68,701	In-water
Confluence of Clearwater and Snake Rivers (Corps)	1997/98	Navigation	215,205	In-water
Greenbelt Boat Basin, Clarkston – Lower Granite Reservoir	1997/98	Recreation	5,601	In-water
Port of Lewiston – Lower Granite Reservoir (Port)	1997/98	Navigation	3,687	In-water
Port of Clarkston – Lower Granite Reservoir (Port)	1997/98	Navigation	12,154	In-water
Lower Granite Lock Approach	1997/98	Navigation	2,805	In-water
Lower Monumental Lock Approach	1998/99	Navigation	5,483	In-water
Lower Monumental Lock Approach (Ice Harbor Reservoir) Lower Granite Lock Approach (Little Goose Reservoir) Clearwater/Snake Confluence and Ports of Clarkston and Lewiston (Lower Granite Reservoir)	2005/2006	Navigation	335.898	In-water

2.4 The PSMP Management Measures

Through a collaborative process that included a series of workshops involving technical experts from the Corps and other agencies, and input from scoping, the Corps developed a broad range of management measures to address identified sediment accumulation problems.

The management measures fall within four general categories: dredging and dredged material management; structural management, system operations management, and upland sediment reduction (Table 2-3). These categories are summarized in the following subparagraphs.

2.4.1 Dredging and Dredged Material Management

Dredging involves physical removal of sediments from one location, and placement of the dredged material in another location. The dredging process typically consists of excavation, transport, and placement of dredged sediments. Excavation may be by mechanical means (i.e., physically scooping sediments with a clamshell or backhoe) or hydraulic dredging, which removes sediment by suction. Once dredged, sediments are transported to a disposal or placement area. Dredged material may be placed in-water or upland, and may be beneficially used for other purposes, such as habitat creation, subject to authority and funding.

2.4.2 Structural Sediment Management Measures

Structural sediment management measures seek to control the location and rate at which sediment is deposited at a specific location, in order to reduce or eliminate the magnitude of the sediment interference with authorized purposes of the LSRP. Examples of structural management measures include weirs or weirs to prevent sediment from accumulating in certain areas, and sediment traps provide a place to collect sediment that may otherwise interfere with authorized purposes.

2.4.3 System Management Measures

System management measures modify reservoir operations (such as pool depth) or facilities so that sediment deposition does not adversely affect authorized purposes. Examples of system operations measures include reconfiguring or relocating navigation facilities, managing reservoir water levels for navigation, and modifying flows to flush sediments from problem areas. These measures would occur within the lower Snake River. The Corps and public port authorities would be responsible for implementing system management measures for their respective facilities.

2.4.4 Upland Sediment Reduction Measures

Upland sediment reduction measures are land management actions intended to reduce the amount of sediment that enters into the lower Snake River systems. Upland sediment reduction measures include site-specific projects such as sediment traps or vegetation filter strips designed to reduce erosion of soil from land into area waterways, and programs aimed at encouraging or requiring such projects. Upland sediment reduction measures are currently implemented throughout the watershed of the lower Snake River. For the purposes of this EIS, agencies and land owners responsible for land management in the basins that drain into the LSRP (including federal and state agencies, tribes, and conservation districts) would continue to implement existing land management programs and practices related to erosion control, consistent with their current authorizations and funding. The Corps would continue implementing erosion and sediment control on its lands adjacent to the LSRP.

Table 2-3. Management Measures

Measure	Description
Dredging and Dredged Material Management	
Navigation and Other Dredging	Dredging typically consists of excavation, transport, and placement of dredged sediments. The excavation process for the lower Snake River involves the removal by mechanical or hydraulic means (e.g., a barge-mounted "clamshell" dredge scooping sediments from the reservoir bottom) to restore the intended dimension or use of the area where sediment has accumulated. This measure would apply to removal of sediments affecting navigation, recreation, or HMU irrigation intakes.
Dredge to improve conveyance capacity	This measure differs from the "Navigation and Other Dredging" measure in that it involves removal of substantially greater quantities of sediments from areas outside the navigation channel, access channel and port berthing areas, and/or recreation facilities. The excavation process involves sediment removal by mechanical means at the Snake and Clearwater Rivers confluence to improve flow conveyance.
Beneficial use of sediment	Beneficial use of dredged material includes a wide variety of options that utilize the dredged material for some productive purpose such as habitat restoration/enhancement, construction and industrial use, etc. This measure views dredged material as a valuable and manageable resource. The Corps has beneficially used dredged material to create fish habitat in the LSRP. Other potential beneficial uses include: habitat restoration/enhancement, beach nourishment, aquaculture, parks and recreation, agriculture, forestry, horticulture, strip mine reclamation, landfill cover for solid waste management, shoreline stabilization, erosion control, construction, and industrial use.
In-water disposal of sediment	In-water placement of dredged material is simply the discharge of dredged material into the waterway for purposes of placement and not for any beneficial use. Typically, dredged material is transported to a previously identified mid-depth or deep water location and released into the water at the upstream end of the deep water area.
Upland disposal of sediment	In upland placement, dredged material is placed on land, above high water, and out of wetland areas. The dredged material is typically placed in a cell behind levees that contain and isolate it from the surrounding environment. The dredged material is dewatered through evaporation and/or settling and discharged as clean water. The Corps has identified the Joso site in Lower Monumental Reservoir as a location where upland disposal of dredged material would occur if it was a selected measure, but may include other sites identified in the future.

Structural Sediment Management	
Bendway weirs	Bendway weirs are rock sills located on the outside of a stream or river bend that are angled upstream into the direction of flow. With the weirs angled upstream, flow is directed away from the outer bank of the bend and toward the point bar or inner part of the bend. This redirection of flow occurs at all stages higher than the weir crest. Where there is sufficient velocity and volume, the redirection of flow generally results in a widening of the channel through scour of the point bar. Bendway weirs are typically used to maintain navigation channels.
Dikes/dike fields	Dikes are longitudinal structures used to maintain navigation channels through effects on channel depth and alignment. Dikes constrict low and intermediate flows, causing the channel velocity to increase within the reach, thereby scouring a deeper channel. Dikes are typically built of rock, but may also be built of sheet piling.
Spillway deflectors	Dam spillway deflectors may be rock or concrete structures located at the base of the dam spillway to dissipate energy and reduce the velocity of the spilling water to minimize the potential for erosion and sediment movement. Spillway deflectors typically focus flow from the spillway into the navigation channel.
Agitation to resuspend	This technique involves the deliberate agitation and resuspension of deposited sediment; the sediment is then carried downriver as part of the suspended load of the river.
Agitation to prevent settling	In this measure, additional energy from propeller wash or other means is put into the water column in specific areas of concern to prevent or reduce the rate of sediment deposition.
Bubble curtains	In this measure, additional energy is put into the water column in specific areas to prevent or reduce the rate of sediment deposition. Air curtains are typically composed of a compressor, delivery pipe, and pipe manifolds. Compressed air is delivered into the water column as bubbles. The rising bubbles produce an upward-moving current field; the energy from the current field helps suspended materials remain in the water column. The system can be configured to form a "wall" of bubbles, where the current field acts to block passage of suspended sediments, form one or more columns of upward current, or form a wider net of bubbles, where the current field keeps fine-grained sediments from reaching settling velocity.
Trapping Upstream Sediments (In-Reservoir)	This measure would create a pit in a depositional part of the upstream reach of a reservoir to trap incoming sediment, thus reducing the sediment available to deposit in other areas where it may interfere with authorized purposes. Sediment would have to be periodically removed from the trap and managed by one of the measures described above (i.e., beneficial use, in-water or upland placement).

System Management	
Modify flows to flush sediment (drawdown)	In this measure, flow would be temporarily modified to increase the capacity of the river system to scour and carry sediment, thereby flushing deposited sediments downstream. The ability of a river system to carry sediment is determined by the river's velocity and volume. Flow modification would be created by a drawdown of the Lower Granite Reservoir (e.g., increasing velocity). Flow modifications would be temporary and could be timed to take advantage of naturally-occurring periods of high and low flows.
Navigation Objective Reservoir Operation	This measure involves operating reservoirs of the LSRP at water surface elevations that would provide a 14-foot deep channel within the Federal navigation channel. The Corps would manage pool levels within the preset operating range for each reservoir to maintain 14 feet of water depth over areas where sediment deposition has occurred in the channel. Currently the Corps operates the LSRP at MOP, or as close to MOP as possible, during the juvenile salmonid outmigration season (typically from April through August, but as late as October in Lower Granite Reservoir), and at varying levels within each reservoir's 3 or 5-foot operating range through the rest of the year. This measure would provide the Corps the option of operating above MOP and even at the upper end of the operating range year-round as needed to maintain the 14 foot deep navigation channel.
Maintain channel at less than a 14 foot depth	Maintaining the navigation channel at a depth less than 14 feet forces the users to adjust their vessels and/or shipping practices to accommodate the new paradigm, or run the risk of running aground on a shoal. Maintaining the federal navigation channel at a less than 14-foot depth could be accomplished through establishing another depth as a minimum (such as 12 foot, 10 foot, etc.), or maintaining the 14-foot channel on a periodic basis with sediment deposition causing areas with less than a 14-foot depth in the interim. This measure could range from maintenance of the navigation channel at another minimum depth to no maintenance of the navigation channel.
Reconfigure affected facilities	Facilities affected by sediment deposition may be reconfigured or otherwise modified to avoid the deposited sediment. This measure could include a range of facility modifications. Water intake structures, mooring facilities, docks, and loading/unloading facilities could potentially be extended to reach out beyond nearshore areas where sediment deposition is occurring. In addition to reconfiguring water intake structures, alternative water sources for irrigation could be explored.
Relocate affected facilities	Facilities affected by sediment deposition may be relocated to avoid recurring problems with sediment deposition. Moving or relocating affected facilities is potentially suitable for commercial navigation facilities, recreational boating facilities, and water intake structures. In addition to relocating water intake structures, alternative water sources for irrigation could be explored.

Raise Lewiston Levee to Manage Flood Risk	The Lewiston levee system is an upstream extension of Lower Granite dam and was designed to protect parts of Lewiston, ID from inundation during the SPF[2]. The confluence of the Snake and Clearwater Rivers at upper reach of the Lower Granite reservoir collects much of the sediment carried into the reservoir. Current analysis indicates that flood risk is within acceptable limits, however if future sediment accumulation changes the flood risk to Lewiston by raising the water level in the reservoir, raising the levee would be an option for reducing flood risk. Location and height of change would be determined through detailed site- and time-specific studies.
Upland Sediment Reduction	
Vegetation filter strips	Vegetated filter strips can provide a buffer between overland flow and waterways; the vegetated filter strips slow the overland flow and remove sediment carried in runoff. The filter strips are generally grass, but can also be forested buffers. The vegetation must be dense enough to slow overland runoff and provide for filtration and settling of sediments and other particulates in the runoff.
Streambank erosion control	Streambank erosion can be controlled through structural measures to stabilize the eroding bank and/or influence the characteristics of the stream that are resulting in the bank's erosion. Traditional methods of addressing streambank erosion often involve armoring the streambanks with riprap or concrete, which can have negative implications for habitat, water quality, and aesthetics. Methods that incorporate natural materials and natural channel design principles can provide effective solutions without the negative impacts of traditional armoring methods. These methods include: Bioengineering – using plant materials to structurally stabilize and reinforce eroding banks. Native revetments – using native materials such as rocks, root wads, and logs to armor banks and deflect flows away from eroding areas of banks. In-stream structures – using rocks and/or logs to stabilize streambeds and banks by directing force of the stream's flow away from the bank.
Forest practices – structural	Structural practices include road construction to maximize self drainage, road removal, post-fire land treatments, and stabilizing and improving channel stability (USFS 2005, University of Arkansas 2006, Elliot et al. 2010).

[2] SPF, or standard project flood, is explained in Section 1.2.

Agriculture – conservation measures	Conservation districts administer a number of conservation programs that directly or indirectly seek to reduce erosion and improve water quality. Physical practices to reduce erosion and improve water quality include no-till cultivation, crop rotation, and/or taking highly erosive farmland out of production. In general, these programs are financial and technical assistance programs whereby farmers and other landowners voluntarily enter into contracts to implement conservation measures. This measure would involve implementation of additional physical practices (beyond current levels) to reduce erosion and improve water quality. In addition, rangeland conservation practices, such as fencing, moving water points away from streams, and streambank stabilization in range areas are actions that can reduce erosion and sedimentation in range and grazing areas.
Forest practices – conservation measures	Forest conservation includes measures such as concentrating vegetation treatments in larger blocks, reducing severe fire risk through prescribed fire and thinning, and protecting and restoring riparian areas (USFS 2005 and University of Arkansas 2006).

SECTION 3.0 IMPLEMENTATION OF THE PSMP

3.1 Determining a Need for Action

Part of the intent of the PSMP is to identify sediment trends that may require management action. This section presents the process for monitoring, identifying, and forecasting sediment accumulation to meet authorized purposes of the LSRP.

The decision will be based on review of monitoring reports and feedback from Engineering and Construction Division and Operations Division. Action will be taken when information indicates a need for sediment management within the foreseeable future to ensure the sediment accumulation will not interfere with authorized purposes of the LSRP. The decision-making process is discussed further in Section 3.2. A summary of the implementation process, including steps, activities, outcomes, and documentation is provided in Attachment A.

3.1.1 "Plan-Level" System Monitoring (Ongoing)

The overall purpose of the monitoring program is to provide a framework to ensure facilities meet their authorized purpose; comply with applicable environmental laws and regulations; and provide feedback to the Corps for improving the long-term sediment management program. The monitoring program is also intended to foster a working relationship with regulators and stakeholders to aid in timely review and increased credibility for the application of individual measures. The Corps will maintain a monitoring program of known problem areas within the system. Through this monitoring, the Corps will be able to determine when and where management actions must be implemented. The data gained through monitoring will also indicate the need for adaptive management under the PSMP. Monitoring of sediment accumulation of the known problem areas will be used to trigger the need for action.

3.1.1.1 Navigation Bathymetric Surveys and Reports

The Corps conducts annual bathymetric surveys of the Federal navigation channel both in the lower Snake River and in the confluence of the Snake and Clearwater Rivers to determine whether the channel meets authorized dimensions. If warranted, the Corps can arrange to have special surveys of isolated sites where problems develop, but the annual surveys are designed to monitor all areas where sediment is expected to impair the navigation channel. The bathymetric data is maintained by the Corps' Operations Division Navigation Coordinator, and are used by the Corps to prioritize maintenance needs. The Corps also periodically surveys fixed sediment range cross sections to monitor long-term sediment accumulation throughout Lower Granite Reservoir.

Port authorities and shipping companies file reports on an as-needed basis when navigation channel conditions result in unsafe conditions for navigation. The Coast Guard also reports on areas of concern for navigation, when encountered. These reports are received and maintained by the Corps' Operations Division Navigation Coordinator.

3.1.1.2 Recreation Boater/Recreational User Reports/Complaints

Reports of obstructions to boating facilities (e.g., boat basins, marinas) are made occasionally to the Corps' Natural Resources Offices at Ice Harbor Dam and Clarkston, Washington. These reports are maintained by the Natural Resource Offices, and are used by the Corps to prioritize maintenance needs.

3.1.1.3 Fish and Wildlife Operations Reports on Water Intakes

The Corps' Natural Resource Managers are responsible for preparation of annual reports of conditions at HMUs, including an assessment of the water intake for irrigation facilities and sediment accumulation. These reports are maintained by the Natural Resource offices and used by the Corps to prioritize maintenance needs.

3.1.1.4 Flow Conveyance

The Corps is responsible for preparation of annual reports of sediment conditions within the Lewiston levee system. These reports are maintained by the Corps' Hydrology and Hydraulics Branch and Dam Safety Officer, and used by the Corps to prioritize maintenance needs.

3.1.1.5 Lower Snake River Monitoring by Others

Other agencies regularly monitor conditions and produce reports used for preparation of sediment management actions. The U.S. Geological Survey (USGS) monitors water surface levels and flow volumes in the lower Snake River and its major tributaries. Other state and local agencies, many represented in the LSMG, also monitor and record information useful for planning and implementing sediment management measures.

3.1.2 Use of Monitoring Reports

It is the goal of this plan to be "proactive" rather than "reactive." The Corps wants to plan and implement actions to reduce the magnitude and frequency of sediment problems, and minimize the environmental effect of needed actions. Therefore, the Corps has identified conditions to serve as triggers for undertaking action pursuant to the plan. This action results in a solution to a problem(s) far enough in advance of a critical phase to allow for planning, design, consultation, and implementation of the corrective measure. Plan-level monitoring will be reviewed on an annual basis to determine where and when action is needed and measure implementation should be initiated.

3.2 PSMP Measure Implementation Process

The measure implementation process for a given project will generally follow the Corps' established planning procedures as outlined in ER 1105-2-100, including problem identification; forecast of future conditions; formulation of alternative correction measures; evaluation and comparison of alternatives (including cost effectiveness and duration); and selection of a measure/plan for implementation leading to final design, contract document preparation, and measure implementation. The implementation process is an ongoing iterative process, as illustrated in Figure 3-1. Each step in the process is described below.

3.2.1 Problem Identification

The Corps will review all monitoring reports to identify locations experiencing sediment accumulation that potentially interfere with authorized purposes, thus requiring corrective action (Table 2-1). Problem identification will include location description; site type/authorized use affected; magnitude of the problem; source of problem, if known; history of previous management/monitoring actions taken; observed trends; and the timeframe for action. Problem identification will allow the Corps to determine timeframes for action and implement specific steps of planning, design, and implementation.

3.2.2 Triggers for Action

The Corps will forecast future conditions without corrective action, using factors such as rate of shoaling, expected increases in navigation incidents, time until problem becomes critical, etc., and will associate a timeframe for action for each identified problem location. For each problem location identified, the Corps will note whether sediment interference with an authorized purpose is currently affecting the purpose or is likely to do so in the future. The forecast of future conditions will be used in selecting appropriate corrective measures and evaluating the potential effectiveness of those measures. The forecast will also consider the timeframe to address the problem. If there is time to develop a solution prior to the problem reaching a critical state, the potential list of correction measures may include solutions requiring a longer implementation time. If the problem poses an emergency condition, the District Commander would proceed as described in Section 3.2.3 Actions in Response to Triggers. There are three levels of triggers: Emergency, immediate need, and future forecast need, and these triggers are also described in Table 3-1.

3.2.2.1 General

- ***Emergency Conditions***. The Corps would declare an emergency if, pursuant to 33 C.F.R 230.8, the following conditions existed.
  - Sediment accumulation is causing or will likely cause unacceptable hazard to human life or navigation
  - Sediment accumulation is causing or will likely cause a significant loss of property
  - Sediment accumulation is causing or will likely cause severe economic hardship

- ***Immediate Need.*** The conditions warranting implementation of an immediate need measure include:
  - Sediment accumulation is currently impairing an authorized project purpose.

- ***Future Forecast Need.*** The conditions warranting initiation of an alternative measures analysis would be based on the following forecasted future conditions:
  - Sediment accumulation that impairs an authorized purpose is recurring at the same location more frequently than once every five years.
  - Sediment accumulation that impairs an authorized purpose is anticipated to occur at a particular location (or locations) in less than five years.

The following sections describe the triggers for each of the four problem area types.

3.2.2.2 Navigation

- ***Emergency Action Triggers.*** **Potential situations that could be considered an emergency for navigation include:**
  - high flows or storm events deposit enough sediment at a point or points in the Federal navigation channel to severely limit or prevent commercial navigation
  - unexpected event in which sediment is swept into a navigation lock approach, forming a shoal that impedes barge access to or from the lock

- ***Immediate Action Triggers.*** Situations triggering the need to take immediate action for navigation include:
  - Navigable depth is less than 14 feet deep at MOP within the Federal navigation channel and is impairing access to port berthing areas
  - Navigable depth is less than 14 feet deep at MOP within the Federal navigation channel and is impairing access to any of the four navigation locks on the lower Snake River
  - Navigable depth in the Federal navigation channel is less than 14 feet deep at MOP and is impairing the safe movement of tug and multi-barge tows and other commercial vessels

- ***Future Action Triggers.*** Navigation situations warranting initiation of an alternative measures analysis include the following forecasted future conditions:
  - Sediment accumulation in the Federal navigation channel is impairing access to port berthing, is impairing access to any of the navigation locks, or is impairing safe movement of commercial vessels is recurring at the same location more frequently than once every five years.
  - Sediment accumulation in the Federal navigation channel that impairs access or safe movement of commercial vessels is anticipated to occur at a particular location (or locations) in less than 5 years.

3.2.2.3 Recreation

- ***Emergency Action Triggers***. Potential situations that could be considered an emergency for recreation include:'
  - Unexpected rapid deposit of sediment at a boat basin entrance posing threat to boaters

- ***Immediate Action Triggers.*** Situations triggering the need to take immediate action for navigation include:
  - Boat basin depths at MOP are less than the original design criteria (how many feet of depth can be lost before boats have problems?) and boats are having difficulty entering and exiting the basin
  - Sediment has built up at entrance to basin, blocking access

- ***Future Action Triggers.*** Recreation situations warranting initiation of an alternative measures analysis include the following forecasted future conditions:
  - Sediment accumulation that blocks or restricts recreational boat access to a boat basin or marina is anticipated at a particular location (or locations) in less than five years or more frequently than every 5 years.

3.2.2.4 Fish and Wildlife

- ***Emergency Action Triggers.*** Potential situations that could be considered an emergency for fish and wildlife include:
  - Irrigation intake fails as the hottest part of the growing season starts and large blocks of habitat are in danger of being lost.

- ***Immediate Action Triggers.*** Situations triggering the need to take immediate action for fish and wildlife include:
  - Sediment has buried an irrigation intake
  - Sediment is clogging an irrigation intake

- ***Future Action Triggers.*** Fish and wildlife situations warranting initiation of an alternative measures analysis include the following forecasted future conditions:
  - Sediment accumulation that interferes with an irrigation intake recurs at the same location more frequently than every five years.
  - Sediment accumulation that interferes with an irrigation intake is anticipated at a particular location (or locations) in less than fi5ve years.

3.2.2.5 Flow Conveyance

- ***Emergency Action Triggers.*** Potential situations that could be considered an emergency for flow conveyance include:
  - Massive amounts of sediment are deposited in the channel near Lewiston that were unmeasured in previous surveys, and

   - Near-term forecasts of flooding and hydraulic modeling indicate a heightened risk of overtopping the Lewiston levees, and
   - The risk of flooding cannot be reduced to acceptable levels with reservoir operations prescribed in the authorized water control manual.

- ***Immediate Action Triggers.*** Situations triggering the need to take immediate action for flow conveyance include:
   - Consecutive surveys show an accelerated rate of sediment accumulation in the channel near Lewiston, and
   - Hydraulic modeling indicates a heightened risk of overtopping the Lewiston levees during extreme floods within 5 years if the rate of accumulation continues, and
   - The risk of flooding cannot be reduced to acceptable levels with normal reservoir operations prescribed in the authorized water control manual

- ***Future Action Triggers.*** **F**low conveyance situations warranting initiation of an alternative measures analysis include the following forecasted future conditions:
   - Consecutive surveys show increasing sediment accumulation in the channel near Lewiston, and
   - Hydraulic modeling indicates a heightened risk of overtopping the Lewiston levees during extreme floods after 5 or more years if sediment accumulation continues, and
   - The risk of flooding cannot be reduced to acceptable levels with normal reservoir operations prescribed in the authorized water control manual.

3.2.3 Actions in Response to Triggers

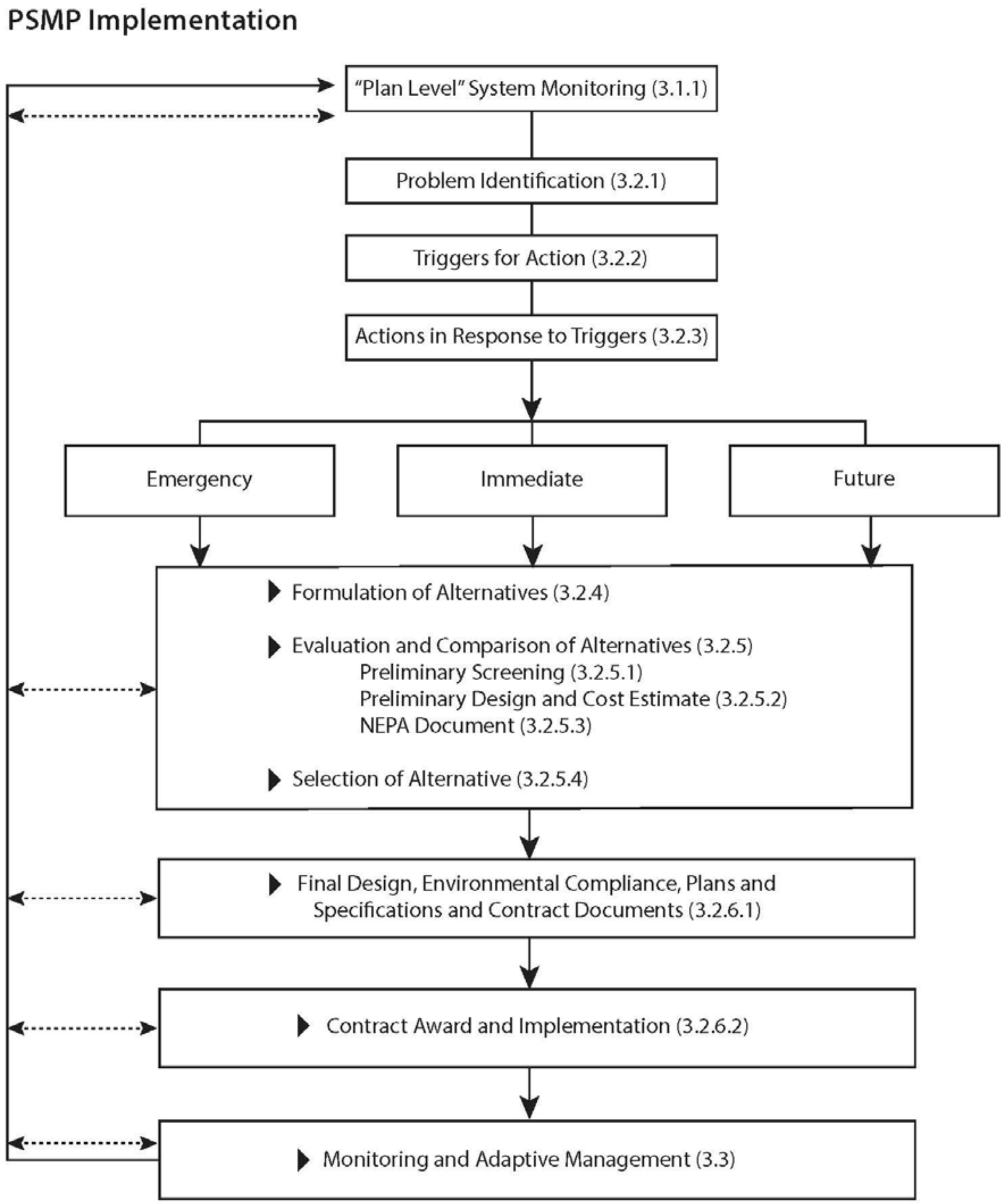
The way in which the Corps responds to triggers will differ based on problem and trigger types.

3.2.3.1 Navigation

- Emergency Condition

  For emergency navigation conditions, the Corps would first implement any appropriate operational changes (i.e., raising the reservoir elevation or modifying water releases at one or more dams) as an interim action. These actions would remain in effect until the Corps could implement an emergency dredging action. This would likely be for a period of a few weeks to a few months, depending upon availability of funding and the time needed to prepare for a dredging action and get a contractor onsite. Under an emergency dredging situation, only the area of immediate concern would be dredged, and the quantities of material removed would likely be small. The dredging method would probably be mechanical, with clamshell dredging the most likely. The disposal site would be decided on a case-by-case basis in accordance with Corps regulations (Federal standard), but could be upland or in-water. If there is time and it is practical, an existing disposal site

Figure 3-1. PSMP Implementation



would be used. The Corps would dredge the problem areas to the usual depth (up to16 feet below MOP). This would allow 1 foot of overdig and 1 foot of advanced measure to extend the time before shoaling may reoccur.

Once an emergency has been declared and the method to address the emergency has been decided, the Corps would take several actions. Stakeholders would be notified of the action planned by the Corps. Applicable environmental compliance would be completed before the emergency action was implemented if possible, or concurrently or after the fact if there is insufficient time to do it prior to the action. The type of NEPA documentation necessary would be decided on a case-by-case basis. Other environmental coordination would be done over the phone or by e-mail if insufficient time exists to prepare written documents. Assuming a contract would be needed to perform the emergency action, the Corps would need to decide what type of contract to use. Engineering and Construction Division would be tasked with preparing plans and specifications, and administering the contract. Contracting would need to expedite the procurement process so a contract could be advertised and awarded quickly. Funding for performing the in-house preparation work and the maintenance action would have to be taken either from the District's budget for that fiscal year (FY), or from other Districts or Northwestern Division. There would not be time to wait to get the funding request in the normal budget cycle.

- *Immediate Need Condition*

Actions taken by the Corps to address an immediate navigation need would be similar to those required for an emergency. The Corps would first implement appropriate operational changes, (i.e., raising the reservoir elevation, adjusting spill patterns, or water releases at one or more of the dams) as in interim action. Before implementing any changes, the Corps would have to review the FCRPS BiOp in effect at the time to determine if the proposed changes would be allowed under the ESA without reinitiating consultation. These actions would remain in effect until the Corps could implement a dredging action to remove the accumulated sediment. This would likely be for a period of 1 to 3 years, allowing time for the Corps to secure funding, prepare plans and specifications, perform necessary environmental compliance, award a contract, and get a contractor onsite. The dredging methods would be similar to those used for an emergency action. Disposal would most likely be for beneficial use, either in-water or upland subject to authority and funding. Environmental compliance would be performed prior to advertising the contract if possible, but must be completed at least before the notice to proceed is given to the contractor.

- *Future Forecast Condition*

  The Corps would implement a feasibility-type analysis when an area in the Federal navigation channel exhibits chronic sediment deposition and the situation is expected to continue. This analysis would follow the process described in Section 3.2.4, and would evaluate a variety of potential management measures to determine the most cost-effective action or action to manage the sediment depositing in that area. These measures could include constructing dike fields or sediment traps. It may take several years to complete the analysis and accompanying environmental compliance and implement the recommended action, subject to authority and funding. While that analysis is being conducted, the Corps may need to go through one or more cycles of interim operations with possible dredging as described for the immediate need.

3.2.3.2 Recreation

- *Emergency Condition*

  Unexpected rapid deposit of sediment at a boat basin entrance posing threat to boaters.

- *Immediate Need Condition*

  Actions taken by the Corps to address an immediate recreation needs would include an interim action and possibly dredging. As an interim action, the Corps may possible post warnings that the boat basin or marina is experiencing shallow water conditions caused by sediment accumulation. If the boat basin or marina becomes too hazardous for boaters, the Corps may close the facility and direct boaters to other nearby facilities. These actions would remain in effect until funding could be secured to perform the planning, environmental compliance and award a contract for a dredging action. This would likely be for a number of years as actions in these areas are funded through the Corps recreation program, which has been experiencing decreases in funding for several years. When any dredging is performed, the dredging and disposal methods would be similar to those used for navigation problem areas.

- *Future Forecast Condition*

  The Corps would implement a feasibility type analysis when a problem area in a boat basin or marina exhibits chronic sediment deposition and is expected to continue to have a problem. This analysis would follow the process described later in Section 3.2.3 and would evaluate a variety of potential management measures to determine the most cost-effective action or action to take. The measures would include sediment management, reconfiguration of the facilities, and possible relocation of the facilities. It may take several years to complete the analysis and environmental compliance and to implement the recommended action. While that analysis is being conducted, the Corps may need to go through one or more cycles of interim operations and possibly dredging as described for the immediate need.

3.2.3.3 Fish and Wildlife

- *Emergency Condition*

If an irrigation intake becomes buried by or clogged with sediment during the peak irrigation season, the Corps would likely take immediate measures to restore the flow of water into the intake. These actions could include lifting the intake out of the sediment if possible, excavating (dredging) to remove sediment, installing a new intake, connecting to another water source, or trucking in water. If the intake is located in a backwater area and the water temperature is above 73 degrees F, the Corps may be able to use hydraulic dredging instead of mechanical dredging to remove the sediment.

- *Immediate Need Condition*

Actions taken by the Corps to address an immediate need for irrigation at an HMU would include the same actions as for an emergency.

- *Future Forecast Condition*

The Corps would implement a feasibility type analysis when an irrigation intake exhibits chronic sediment deposition and is expected to continue to have a problem. This analysis would follow the process described later in Section 3.2.3 and would evaluate a variety of potential management measures to determine the most cost-effective action or action to manage the sediment depositing in that area. It may take several years to complete the analysis and environmental compliance and to implement the recommended action. While that analysis is being conducted, the Corps may need to go through one or more cycles of interim operations and possibly dredging as described for the immediate need.

3.2.3.4 Flow Conveyance

- *Emergency Condition*

Emergency actions for flow conveyance would include extraordinary reservoir operations, such as advanced lowering of the reservoir water surface, that are not currently authorized by the water control manual. Following the flood, the bathymetry of the confluence area would be surveyed and new hydraulic models developed. If the hydraulic modeling indicates that an unacceptable risk of overtopping the levees remains, conveyance dredging would be performed as soon as practicable to reduce the risk during subsequent flood events

- *Immediate Need Condition*

  Actions taken by the Corps to address an immediate flow conveyance condition would likely be conveyance dredging with a possible advanced lowering of the reservoir water surface level when high flows are expected. Conveyance dredging would be similar to that for navigation and would include beneficial use of the dredged material subject to authority and funding. It would likely take 1-3 years to perform the dredging.

- *Future Forecast Condition*

  The Corps would implement a feasibility type analysis when flow conveyance is being adversely affected by sediment deposition and hydraulic modeling indicates that the risk of overtopping the levees is unacceptable. This analysis would follow the process described in Section 3.2.3 and would evaluate a variety of potential management measures, including dredging and raising the levees, to determine the most cost-effective action or action to manage the sediment depositing affecting flow conveyance. It may take several years to complete the analysis and environmental compliance and to implement the recommended action. While that analysis is being conducted, the Corps may need to go through one or more cycles of interim operations and possibly dredging as described for the immediate need.

3.2.4 Formulation of Alternatives for Future Need Actions

When a problem area meets a trigger for a future need action, location-specific alternatives for addressing the problem will be formulated and will draw from the list of measures noted below. As part of the PSMP EIS process, the Corps identified feasible and effective measures to address anticipated sediment accumulation problems within the LSRP.

If the sediment interference with an authorized purpose is currently occurring or is likely to occur in the future, the Corps will begin the formulation, evaluation, and selection of alternatives. The formulation of alternatives will consider the least costly, an environmentally acceptable manner, consistent with engineering requirements, and the urgency of the need to correct the problem. An alternative may be composed of a single measure or a combination of measures. Many of the measures considered have specific implementation time requirements, either short term or long term. For example, the Corps' historical method of dredging accumulated sediments and utilizing the dredged material for beneficial uses has proven to be a measure that can reasonably be implemented in the short term. Also, some system management measures such as keeping pool levels above MOP have been implemented in the short term to address immediate problem needs. Other measures such as installation of bendway weirs and dike fields, or relocation of affected facilities may require more lead time to accommodate design and model testing or negotiations with shippers, as well as the time for the effectiveness of the measure to be established. The alternatives selected for further consideration should be able to address the problem within the time frame defined by the problem identification and forecast of future conditions.

3.2.5 Evaluation and Comparison of Alternatives

Measures considered appropriate for further consideration must be evaluated against screening criteria noted below. Those measures that meet the screening criteria are then developed to a preliminary design detail and cost estimate and comparatively evaluated through the NEPA process. The end result is selection of an alternative for project implementation.

3.2.5.1 Preliminary Screening

The final selection of a measure(s) for implementation will be dependent on the results of screening alternative measures. Each measure would be evaluated on each of the following screening criteria:

- Does the measure (or grouping of measures) correct the problem within the desired timeframe to prevent interference with authorized purposes of the LSRP?
- Is the measure consistent in scale with the identified problem?
- Is the measure cost effective (considering short-term and long-term costs and benefits)?
- Does the measure pose any likely significant adverse environmental effects?
- Does the measure have any likely adverse effects on other authorized project purposes?

For each question, the Corps will need to provide a qualitative answer. The screening is a qualitative approach to “winnowing” the range of options for addressing each sediment accumulation problem, and forms the basis for the selection of an alternative (or alternatives) to advance into further planning and design. Attachment B of this plan provides an Alternative Measures Preliminary Screening worksheet to evaluate measures considered for project-specific implementation. The list of measures below in Table 3-1 shows the applicability to effect the sediment accumulation related to the authorized purposes.

Design and cost estimates will be carried to a 15% level of design detail for major features. The project features will be defined in such a manner that allows the performance output and the impacts associated with the measure to be quantified.

Table 3-1. Management Measures

Measure	Applicability to Authorized Purpose			
	Navigation	Recreation	Fish & Wildlife	Flow Conveyance
Dredging and Dredged Material Management				
Navigation and Other Dredging	Yes	Yes	Yes	Yes
Dredge to improve conveyance capacity	Yes	No	No	Yes
Beneficial use of sediment	Yes	N/A	Yes	Yes
In-water disposal of dredged material	Yes	Yes	Yes	Yes
Upland disposal of dredged material	Yes	Yes	Yes	Yes
Structural Sediment Management				
Bendway weirs	Yes	No	No	No
Dikes/dike fields	Yes	No	No	No
Agitation to resuspend	No	Yes	Yes (partial need flow)	No
Trapping Upstream Sediments (In-Reservoir)	Yes	No	No	Yes
System Management				
Modify flows to flush sediment (drawdown)	No			Yes (partial medium/higher flows are better)
Navigation Objective Reservoir Operation	Yes	Yes	No	No
Reconfigure affected facilities	No	Yes	Yes	No
Relocate affected facilities	Yes	Yes	Yes	N/A
Raise Lewiston Levee to Manage Flood Risk	No	No	No	Yes
Upland Sediment Reduction Measures				
Vegetation filter strips	No	Yes	Yes	No
Streambank erosion control	No	Yes	Yes	No
Forest practices – structural	No	Yes	Yes	No
Agriculture – conservation measures	No	Yes	Yes	No
Forest practices – conservation measures	No	Yes	Yes	No

3.2.5.2 Preliminary Design and Cost Estimate

Design and cost estimates will be carried to a 15% level of design detail for major features. The project features will be defined in such a manner that allows the performance output and the impacts associated with the measure to be quantified.

3.2.5.3 Environmental Compliance Documentation

Environmental compliance for future need actions will be done on a case-by-case basis. A project-specific NEPA document that is tiered off of the PSMP EIS will be prepared to document the problem identification, environmental analysis, and comparison of alternatives (measures). The specific document to be prepared [EA or supplemental EIS (SEIS)] will be determined by the Corps based on NEPA regulations in effect at that time.

Compliance with ESA will be done each time the Corps proposes to implement an action and would be done for the preferred alternative/selected action. If the Corps determines the action would have no effect on any listed species or their critical habitat, the Corps would prepare a memo to that effect for the file. If the Corps determines the action is likely to affect a listed species or their critical habitat, the Corps would prepare a biological assessment (BA) and submit the BA to National Marine Fisheries Service and/or U.S. Fish and Wildlife Service with a request for consultation. Consultation would be either informal or formal, depending upon the severity of the effects ("take" or no "take").

"Take" is defined as any action to kill, harm, harass, pursue, hunt, shoot, wound, trap, capture, collect, or attempt to engage in any such conduct. If the project is not likely to adversely affect a listed species or critical habitat (cause no "take"), informal consultation would be conducted; resulting in a concurrence letter(s) from the Service(s). If the action is likely to adversely affect a listed species or critical habitat (causes "take"), formal consultation would be conducted; resulting in a biological opinion(s) from the Service(s).

Compliance with Section 106 of the National Historic Preservation Act would also be performed each time the Corps proposes to implement an action and would be done for the preferred alternative/selected action. The Corps would first determine if there was the potential to affect historic properties. If there was no potential, the Corps would prepare a memo to the file documenting that determination. . If there was a potential, the Corps would determine whether or not the effects were adverse. In accordance with 36 CFR Part 800 the Corps will provide any determinations of no adverse effects to the appropriate consulting parties to allow for comment. If the effects are determined to be adverse the Corps would make every effort to avoid the effects. If effects cannot be avoided the Corps would consult with interested parties to develop a memorandum of agreement to mitigate the effects.

Compliance with Section 404 of the Clean Water Act (CWA) would be considered each time the Corps proposes to implement an action and would be done for the preferred alternative/selected action, if applicable. CWA compliance would be required for placement of fill or dredged material below the ordinary high water mark (maximum pool elevation in the reservoirs). The Corps would first determine if the action is exempt from Section 404. If the action was not exempt, the Corps would determine if it met the conditions for a nationwide permit. If the action did not meet the conditions for a nationwide permit, the Corps would prepare a Section 404(b)(1) evaluation. The Corps would send the 404(b)(1) evaluation to the appropriate state agency along with a request for Section 401 Water Quality Certification and would circulate a Public Notice describing the in-water work. If the action met the conditions of a nationwide permit, but not the 401 certification for that permit, the Corps would request 401 certification from the state without preparing a 404(b)(1) evaluation or circulating a Public Notice.

The Corps would comply with other appropriate environmental laws, as needed.

3.2.5.4 Selection of Alternative

The alternatives will consider the least costly, an environmentally acceptable manner, consistent with engineering requirements, and the urgency of the need to correct the problem. Following evaluation and comparison of alternatives which will be summarized in the project-specific NEPA document, the District Commander will select the alternative to be implemented. This decision will be documented in either a Finding of No Significant Impact (FONSI) if an EA is prepared or a ROD if SEIS is prepared. The selected alternative will then be advanced into final design and implementation.

Table 3-1 presents an example of the process that follows problem identification and forecasting future conditions in order to initiate the "planning" steps described above. The sites presented in the table are actual locations within the LSRP and are in order of anticipated priority based on information available at the time of development of this PSMP. The table will be updated in the first quarter of every fiscal year based on the results of the annual monitoring reports (Section 3.2.1). The "design" and "implementation" steps indicated in the table are described in the sections following.

3.2.6 Final Design and Implementation

Based on the outcome of the steps noted in sections 3.2.3 and 3.2.4, the Corps would advance a specific selected alternative composed of a measure or measures, into final design and implementation as described in the following sections.

3.2.6.1 Final Design, Plans, Specifications and Contract Documents

Once an alternative has been selected for implementation, final design and modeling would be conducted as appropriate, plans and specs developed, and contract documents prepared as applicable.

- Design and Cost Estimates (ER 1110-1-1300)
- Plans, Specifications and Contract Documents

3.2.6.2 Alternative Implementation

The Corps, in coordination with other parties as applicable, will implement the alternative selected to address sediment accumulation at the subject location(s). Post-implementation monitoring will be conducted in order to evaluate effectiveness of the alternative implemented.

3.3 Monitoring and Adaptive Management

The overall purpose of the monitoring program is to provide a framework that will: ensure compliance with applicable environmental laws and regulations; assess the effectiveness of a measure; and provide feedback to the Corps to improve the long-term sediment management program. The monitoring program is also intended to facilitate a working relationship with regulators and stakeholders that will aid in timely review and increased credibility for application of individual measures.

The monitoring strategy will encompass three key monitoring and evaluation components:

- Project-specific monitoring for implementation and sediment management effectiveness.
- Project-specific monitoring for regulatory and environmental compliance.
- Validation monitoring for the overall adaptive management program.

Adaptive management is a systematic process that is developed to continually improve management policies and practices by learning from the results of implemented measures. After a measure has been implemented the Corps would monitor and assess the effectiveness of the measure. Updates to the PSMP to adapt measure implementation would be made as indicated by monitoring program results.

3.3.1 Project Specific Implementation and Effectiveness Monitoring

The intent of the Project-Specific Monitoring Program is to combine the implementation and effectiveness monitoring and regulatory monitoring requirements, and to provide a framework for program evaluation and feedback. This section outlines the process for establishing objectives, undertaking monitoring activities, and evaluating the resulting data for each applied measure. The Corps' technical specialists will be responsible for coordinating monitoring and evaluation activities. Where appropriate, the LSMG, and federal, state, and local agencies and Tribes may be involved in coordination of monitoring activities.

Project-specific monitoring must address four data categories, as follows:

- Implementation – was the measure implemented in accordance with the Corps plan and/or design?
- Effectiveness – did the measure achieve its objective, e.g., did it effectively address the target sediment problem or other project objective?
- Efficiency – is the measure cost effective in addressing the target sediment management or other project objective?
- Compliance – is the implementation of the measure in compliance with applicable environmental requirements? Possible monitoring characteristics include:
  - Sediments (dredged material)
  - Water quality

- Physical stability or movement of the disposed material (e.g., sediment migration)
- Biological processes (e.g., fish production) and habitat quality
- Cultural resources.

Each of these categories requires different levels of data collection. For example, the dredged material testing involves a pre-determined, quantifiable analysis that is generally accepted by the regulatory community. On the other hand, monitoring biological processes, such as juvenile fish recruitment at areas of created habitat may need to be more flexible, with consideration given to location, season, species mix, and other factors.

This Monitoring Program process presents a series of "steps" that would apply to each application of a management measure regardless of the data category being monitored (e.g., water quality, biological). The results of each project-specific application of a management measure will be evaluated and fed back into the next process, creating an iterative process. Although each application of a management measure will be distinct, there will be similarities in data collection and evaluation. These steps are described below and illustrated in Figure 3-2.

3.3.1.1 Step 1. Define the Project and Identify Objectives

Prior to the initiation of the selected alternative, it is important to identify project goals and the baseline from which monitoring data will be evaluated. At this point, the Corps will identify a team responsible for monitoring activities. The Corps will determine the schedule and budget for monitoring and, if resources are limited, will prioritize the monitoring activities.

- **Identify Physical Boundaries -** The physical boundaries of the project will be set. For example, if dredging has been selected, determine how much material should be removed and from where. At this point, the team can either perform the dredged material sampling in accordance with the Sediment Evaluation Framework in effect at that time or identify alternative disposal locations (i.e., upland) based on the results of this testing. The disposal locations will also be identified.

- **Determine Project Objectives** - Project objectives will be developed for each of the required data categories. These objectives can range from meeting regulatory requirements to assessing the stability and/or environmental benefits of a beneficial use of dredged material. These objectives may be relatively straightforward, such as meeting the requirements outlined in the framework or criteria in state water quality standards. Conversely, other objectives may be to improve salmonid rearing habitat. In these cases, input from the regulatory agencies may need to be considered during the development of project objectives. Some regulatory agencies, such as NMFS, will require consultation prior to any dredging activity.

3.3.1.2 Step 2. Set Goals and Define Criteria

- **Determine Project Goals -** Goals will stem from the objectives. There can be several goals for each objective. For example, if the objective is to improve juvenile salmonid habitat, then the goals could be:

  - Recruit a certain density of macroinvertebrate species (food) that will support corresponding number of fish
  - Provide instream habitat that will encourage juvenile salmonid use of area
  - Minimize mortality of juvenile salmonids due to predation
  - Increase the riparian structure
  - Set Monitoring Parameters and Criteria

- Monitoring parameters and success criteria will then be developed based on the project goals. The monitoring parameters should be selected so that they can "answer" the goal statement. For example, if one of the goals is to improve salmonid rearing habitat, this step should focus on identifying the information that would be needed to determine if rearing habitat is improved.

- **Define Criteria -** Success criteria (that is, criteria that define goals have been successfully met) should also be developed at this time. Defining these criteria will also help determine the data parameters and collection frequencies. Some parameters may require one sampling event, while others may have to be sampled monthly for five years to obtain enough data for credible analysis.

- For macroinvertebrates, the criteria could be considered successful if desired densities of various species are reached (e.g., X individuals/square meter), or where there is an increase in number over the pre-construction condition.

- For some monitored parameters, statistical evaluation based on set criteria (e.g., water quality standards) is possible. For subjective parameters, descriptive measures can be used to provide a rating of parameters (e.g., that meet, do not meet, or exceed expectations).

3.3.1.3 Step 3. Develop Sampling and Analysis Plan

A Sampling and Analysis Plan (SAP) should be developed that details procedures for sampling and analysis by parameter as required. The type, frequency, and duration of sampling should be outlined in the plan as well as analysis procedures. The SAP should include a budget, cost estimate for data collection, and schedule. The SAP should also outline the procedures for data Quality Assurance and Control (QA/QC) as well as data management. Data management will be a crucial component for effective analysis.

3.3.1.4 Step 4. Implement Sampling and Analysis Plan

- **Monitoring** - During monitoring, the Corps' project manager and technical specialists should systematically check the items identified in the SAP to ensure that they are being completed, including data QA/QC and database management.

- **Interim Analysis and Activity Modification -** Where possible, data gathered during ongoing activities (e.g., water quality) should be evaluated to determine if goals (e.g., water quality standards) are being met. If needed, the project activities may need to be modified to meet target goals. Sampling should confirm that these goals are met.

3.3.1.5 Step 5. Analyze Results

After the management measure has been implemented, the focus of the process will be on completing data collection and evaluating the monitoring data. Depending on the management measure applied, this could continue for several years in accordance with the goals and criteria set forth before the management measure began.

- **Continued Monitoring -** While some data collection may end after the completion of activities, some monitoring will continue. Each data category should include a timeline for sampling and analysis. In some cases, this monitoring could last from one additional year to ten years or more, depending on the goals and criteria. For example, collecting data on the evaluation of upland sediment reduction measures may take several years, while collecting data pertaining to juvenile salmonid use of an area may be sufficient after one or two years.

- There should also be a method in place that will allow data collection to end prior to scheduled completion, if the success criteria have been met. For example, it may have been estimated that it would take five years to establish habitat to support rearing juvenile salmonids, but after three years, data may show that habitat is stabilized and juvenile salmonids are indeed using the area consistently.

3.3.1.6 Step 6. Provide Feedback

- **Provide Feedback on Data Analysis -** The data will be evaluated in accordance with the SAP, and the procedure for data evaluation (i.e., statistical analysis) predetermined. For each monitoring parameter, a determination should be made as to whether the success criteria were met. If the data are not sufficient or are too varied to make this determination, this will be acknowledged and recommendations for future collection presented.

3.3.2 Project-Specific Compliance Monitoring

Project-specific applied measures will also be monitored for compliance with applicable environmental regulations and requirements. Specific monitoring requirements and protocols would be identified in the environmental compliance documentation for the action including the ESA consultation for the action, Sediment Evaluation Framework, the 404(b)(1) evaluation, the Section 401 Water Quality Certification, and Section 106 Cultural Resources Consultation. Other specific requirements or protocols may also be established based on the selected measure and its site specific application.

3.3.3 Validation Monitoring for the Overall Adaptive Management Program

Validation monitoring and evaluation occurs at the program level; this monitoring will provide information to determine whether the initial approach and analyses used in development of the adaptive management plan are correct, or to support modifications in the Programmatic Sediment Management Plan (e.g., adaptive management). The program level validation monitoring includes:

- Status and trend monitoring to determine long term trends in sediment conditions in the LSRP.
- Periodic review of the screening criteria used in selecting measures for application within the plan.
- Continual review of the project-specific monitoring results to ensure that appropriate measures are being applied effectively.

The Corps will conduct status and trend monitoring to determine trends in sediment conditions, including trends in sediment recruitment, transport, and deposition within the LSRP. The purpose is to provide the Corps with an understanding of how critical sediment resources (particularly unwanted sediment deposition) are generally trending under the influences of PSMP implementation, other human activities, and environmental factors. Specific factors to be monitored will include basin land use trends, natural and/or man-made disturbances that affect sediment recruitment such as high flows, landslides, or forest fires, watershed sediment management efforts, and the incidence, rate, and scale of unwanted sediment deposition within the reservoirs.

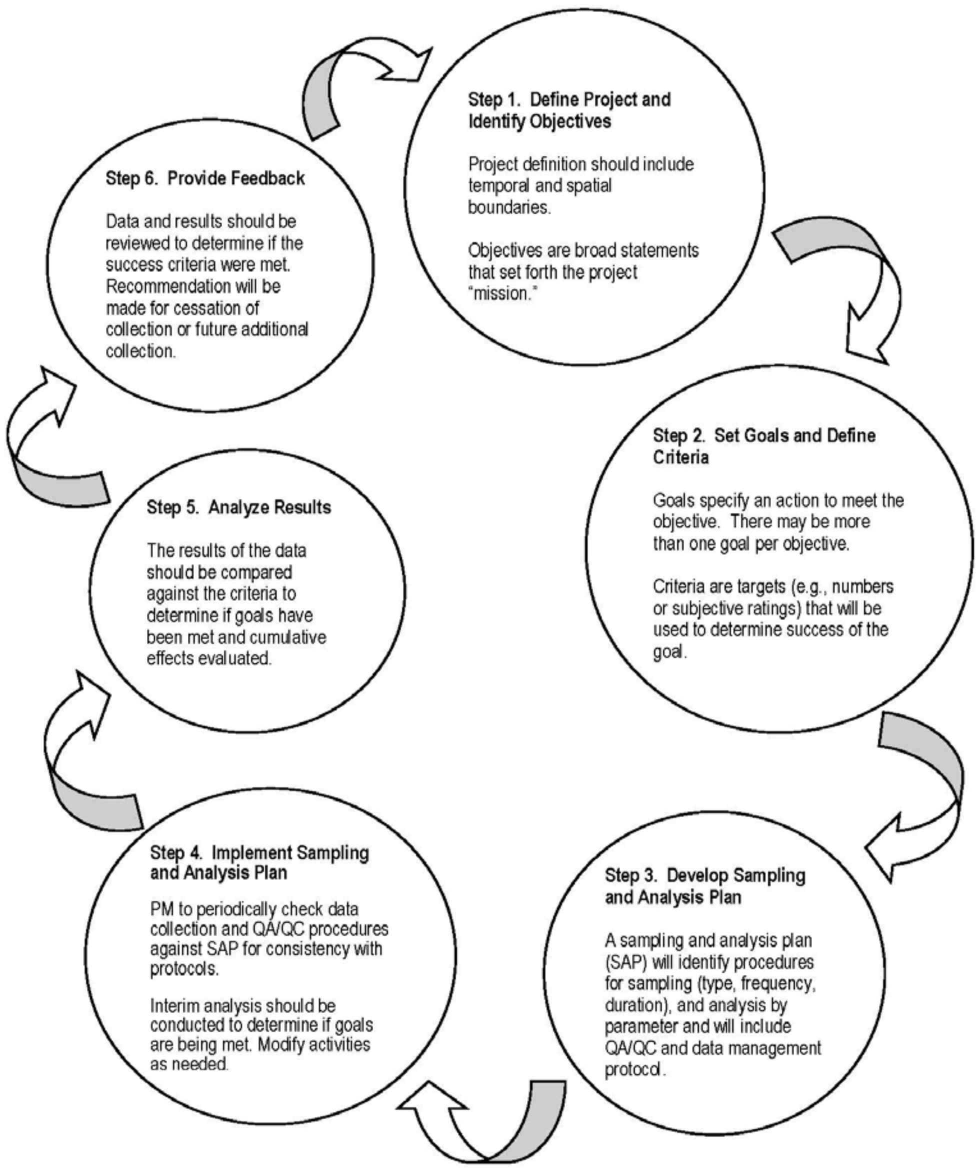
The Corps will also conduct periodic reviews of the screening criteria used in selecting measures for application within the plan. Changes in the FCRPS Biological Opinions or related requirements, changes in status of ESA-listed species, changes in water quality requirements, or the addition of new requirements that affect the selection and application of management measures will be evaluated as they occur.

The Corps will also consider the results of project-specific monitoring in terms of the performance of the measure within the overall program. After a measure is applied and the project and its project-specific monitoring are completed, the Corps will review the performance of the measure to determine its continued applicability within the overall program.

The Programmatic Sediment Management Plan will be modified as necessary to reflect the changing circumstances, requirements, or performance. Modification of the PSMP could include:

- Modifying how a measure is applied (e.g., adapting where, when, how, or why a measure is applied).
- Changing which management measures are considered for possible implementation, e.g., some measures may be dropped from further consideration or use, and other measures added as necessary.
- Specific applications of measures will continue to go through the appropriate and required project-specific engineering and environmental reviews in accordance with federal, state, and local requirements and Corps guidelines.

Figure 3-2. Monitoring Program Steps



3.3.4 Evaluation of the Applied Measure

The most important component of the Monitoring Program is the project evaluation and feedback. For each objective, the evaluation should determine if the project was successful, not successful, or inconclusive. This information should be relayed to other technical staff in the Corps responsible for the overall PSMP.

The data, criteria, and goals should be evaluated for applicability to other PSMP projects. For each set of data collected, an analysis should determine the results that would be applicable to other projects. Continuing the example of beneficial use of dredged material to improve salmonid rearing habitat, if macroinvertebrate recruitment was found to be successful, the next dredging project could use similarly sized substrate, water depth, velocity, and organic materials. If the goal was not a success, the process and results should be evaluated and recommendations made for future projects. This information could be used to modify the project description, location, or methods of data collection for the next application of the management measure.

SECTION 4.0 REPORTING AND UPDATES

4.1 Reporting

After a measure has been implemented and has, through monitoring, been determined effective or not effective, reporting the measure and its success is essential to the adaptive management process. After a measure has been implemented, a report detailing specifics of environmental conditions requiring management, details of the measure implemented, the monitoring program established, and results of the first monitoring effort should be prepared. Bi-yearly monitoring reports should be prepared for the first 2 years following implementation, or whenever conditions change significantly and warrant immediate consideration of changes to the PSMP. After 2 years of monitoring, reporting may be conducted on an annual basis. All reports will be tracked and results compiled with other measure implementation reports for consideration as recommended changes to the PSMP.

4.2 Coordination with Other Stakeholders

Coordination with other land management agencies and groups within the watershed is an integral part of the watershed approach to the PSMP. As such, the Corps will organize annual meetings with all applicable land use management agencies and groups through the annual LSMG meeting. The purpose of the meeting will be to share data and compare trends observed by each agency, identify where additional resources are needed, and analyze trends on a watershed basis. Information gained from meeting participants may result in adapting measures for the implementation process within the PSMP. Protocols for monitoring effectiveness of the agencies' BMP's will be established within the first year of PSMP implementation.

4.3 PSMP Update

The PSMP will be reviewed annually, appended as applicable, and updated at least every 5 years based on monitoring results of implemented measures. The Corps will initiate and facilitate the annual reviews, as well as oversee the plan updates. The PSMP may also be revised whenever the Corps determines that conditions (physical, political, or budgetary) in the area covered by the PSMP have changed significantly enough to warrant an update to the plan. Plan updates may require additional environmental compliance.

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Attachment A: Implementation Process Summary

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IMPLEMENTATION STEP	ACTIVITIES/OUTCOME	DOCUMENTATION
Plan Level System Monitoring (3.1.1)		
On-going surveys	Conduct annual bathymetric surveys of the navigation channel in the Lower Snake River and confluence of the Snake and Clearwater Rivers to identify areas where sediment is accumulating. Communicate regularly with Ports/Shippers Corps Resource Managers monitor conditions at water intakes for HMU irrigation facilities Communicate with other agencies at annual meeting or as needed; review their monitoring records/data	Bathymetric survey data reports Unsafe navigation condition reports from Port Authorities and Shippers Annual reports of conditions of HMUs including water intakes Incorporate other agency data into PSMP when the data indicates sediment migration/accumulation trends
Problem Identification (3.2.1)		
Review compilation of monitoring reports	Identify sediment accumulation problem locations with likelihood of interfering with authorized purposes	Annual PSMP update report that documents: • location description • site type/authorized purpose affected (e.g., navigation, recreation, etc.) • magnitude of problem (i.e., the quantity of accumulating sediment at a particular location) • source of problem, if known • history of previous management/monitoring actions • rate of sediment accumulation and other observed trends
Forecast Future Conditions (3.2.2)		
Forecast future conditions without corrective action	Based on historical and current monitoring data, estimate rate of accumulation that interferes with authorized purposes. Determine timeframe for needed action – i.e., when will accumulation interfere with an authorized purpose (0-3, 3-5, 5+years)	Future conditions Memo for Record (attachment to Annual PSMP update report)
Formulation of Alternatives (3.2.4)		
Develop alternatives that would potentially address location specific sediment problem	Using information provided in the Future Conditions tech memo, determine applicable and feasible measures from Table 2-3 of PSMP Determine alternatives by either combining measures or using variations of an individual measure	Alternatives formulation Memo for Record

IMPLEMENTATION STEP	ACTIVITIES/OUTCOME	DOCUMENTATION
Evaluation and Comparison of Alternatives (3.2.4)		
Preliminary screening (by site)	Preliminary environmental, engineering, and economic analysis Apply screening criteria Dismiss measures not applicable/infeasible Retain applicable and feasible measure(s) as alternatives for further evaluation	Screening Checklist (PSMP attachment B) Memorandum for Record
Preliminary design, cost estimate, and NEPA review	Develop sufficient design (15%) of retained measure(s) for comparative analysis of alternatives* Conduct environmental, engineering, and economic (cost) analyses Prepare NEPA document	Conceptual design Applicable engineering analysis (e.g., hydraulics & hydrology) Cost effectiveness and incremental cost analysis Environmental Assessment (EA) or Environmental Impact Statement (EIS)
Environmental compliance	Ensure any permit applications and consultations have been completed (e.g., Clean Water Act Sections 401 and 404(b)(1), National Historic Preservation Act Section 106)	Regulatory Approvals
Select alternative	Based on preceding step, select sediment management alternative to design and implement	Finding of No Significant Impact (FONSI) for EA; or Record of Decision (ROD) for EIS or SEIS
Final Design and Implementation (3.2.5)		
Design	Develop final design and cost estimates	Final plans and cost sheets
Plans/Specs/Contracts	Develop final plans and specs Award contract(s)	Plans and specs Applicable contract(s)
Implementation	Implement selected alternative	Construction monitoring data and reports
Monitoring and Adaptive Management (3.3)		
Monitor to assess effectiveness of implemented measures and adapt procedures as indicated	Monitor implemented alternative effectiveness and environmental conditions Integrate information into annual monitoring reports Adapt management practices accordingly Meet annually with LSMG and other agencies	Annual reports PSMP updates

*At a minimum, if a tiered EA, SEIS, or EIS is being developed

Attachment B: Alternative Measures Preliminary Screening

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Problem area being evaluated: ____ **Date**: ________ **Evaluator(s)**: ___________________________________

For each question below, answer yes or no as applicable to each measure for the problem area being evaluated. Provide brief basis for your answer in the "Notes on screening"; use additional space at bottom if needed.

1. Does the measure (or grouping of measures) correct the problem within the desired timeframe to prevent interference with authorized purposes of the Lower Snake River (i.e., 0-3 years, 3-5 years, longer than 5 years)? (Please indicate applicable timeframe.)
2. Is the measure consistent in scale with the identified problem?
3. Is the measure cost effective?
4. Does the measure pose any likely significant adverse environmental effects?
5. Does the measure have any likely adverse effects on hydropower or other authorized project purposes?
6. Based on the answers above, is this measure feasible for addressing the noted problem area sediment accumulation?

Notes on Screening: It is very important to thoroughly document the methods/tools used and considerations made as part of the screening. Provide as much information as possible on the rationale for the answers to questions; what analyses may have been conducted, etc. to provide a record of alternative evaluation for each location.

Management Measures	1. Correct problem within desired timeframe?	2. Consistent with scale of problem?	3. Cost effective?	4. Likely significant adverse environmental effects?	5. Adverse effects on authorized purposes?	6. Feasible and reasonable for addressing identified problem?	Notes on screening (use additional space below if needed)
☐ Navigation Channel and Other Dredging							
☐ Beneficial Use of Sediment							
☐ In-water Disposal of Sediment							
☐ Agitation to Resuspend Sediment							
☐ Bendway Weirs							
☐ Dikes and Dike Fields							
☐ Reservoir Drawdown to add Conveyance Capacity							
☐ Modify Flows to Flush Sediment							
☐ Modify Reservoir Level Operation							
☐ Reconfigure Affected Facilities							
☐ Dredging to Improve Flow Conveyance Capacity							
☐ Upstream Sediment Traps							
☐							
Raise Levees							
Upland Disposal							
(Add any others from list in most recent version of the draft EIS)							

Additional documentation:

Appendix B: Investigation of Sediment Source and Yield, Management, and Restoration Opportunities within the Lower Snake River Basin

Prepared by Tetra Tech, 2006

Investigation of Sediment Source and Yield, Management, and Restoration Opportunities Within the Lower Snake River Basin

Prepared by
Tetra Tech EC, Inc.

April 2006

Submitted to
Walla Walla District
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CONTENTS

TABLES

FIGURES

CHARTS

ACRONYMS

AWQMAP	Agricultural Water Quality Management Area Plan
BLM	USDI Bureau of Land Management
BMPs	Best Management Practices
BPA	Bonneville Power Administration
CCRP	Continuous Conservation Reserve Program
cfs	cubic feet per second
Corps	U.S. Army Corps of Engineers
CREP	Conservation Reserve Enhancement Program
CRITFC	Columbia River Inter-Tribal Fish Commission
CRP	Conservation Reserve Program
CWA	Clean Water Act (Federal)
EA	Environmental Assessment
EDT	Ecosystem Diagnosis and Treatment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
ESA	Endangered Species Act of 1973
Forest Service	USDA Forest Service
FOTG	NRCS Field Office Technical Guides
FSA	Food Security Act of 1985
GIS	Geographic Information System
HB	House Bill
HCC	Hells Canyon Complex
HUC	Hydrologic Unit Code
IAC	Interagency Committee
ICBEMP	Interior Columbia Basin Ecosystem Management Project
IDAPA	Idaho Administrative Procedures Act
IDEQ	Idaho Department of Environmental Quality
INFISH	Inland Native Fish Strategy (similar to PACFISH, but for non-anadromous fish)
IPC	Idaho Power Company
ISCC	Idaho Soil Conservation Commission
mg/l	milligrams per liter
MUSLE	Modified Universal Soil Loss Equation

MMBF	Million Board Feet
NAWQA	National Aquatic Water Quality Assessment
NMFS	National Marine Fisheries Service
NPPC	Northwest Power and Conservation Council (formerly Northwest Power Planning Council)
NRCS	US Natural Resource Conservation Service
NTU	Nephelometric Turbidity Unit
ODEQ	Oregon Department of Environmental Quality
OWEB	Oregon Watershed Enhancement Board
PACFISH	Decision Notice for the Interim Strategies for Managing Anadromous Fish-Producing Watersheds in Eastern Washington, Eastern Oregon, Idaho, and Portions of California to protect salmon within that habitat
PCSRF	Pacific Coastal Salmon Recovery Fund
PIBO	PACFISH/INFISH Biological Opinion
PL	Public Law
RHCAs	Riparian Habitat Conservation Areas
RM	River Mile
RMOs	Riparian Management Objectives
RMZ	Riparian Management Zones
PSMP	Programmatic Sediment Management Plan
RUSLE	Revised Universal Soil Loss Equation
SCS	USDA Soil Conservation Service
SPZ	Stream Protection Zone
SRFB	Salmon Recovery Funding Board
SWCA	NRCS Soil and Water Conservation Assistance Program
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USBWPTT	Upper Salmon Basin Watershed Project Technical Team
USDA	U.S. Department of Agriculture
USDI	U.S. Department of Interior
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WDOE	Washington Department of Ecology
WEPP	Water Erosion Prediction Project

WHIP	Wildlife Habitat Incentives Program
WQMP	Water Quality Management Plan
WRIA	Water Resource Inventory Area
WRP	Wetlands Reserve Program
WSU	Washington State University
WVIC	Wallowa Valley Improvement Canal
WAC	Washington Administrative Code

1. INTRODUCTION

1.1 BACKGROUND

Since construction of its first dam on the lower Snake River, the U.S. Army Corps of Engineers (Corps) has recognized that sediment management would be an ongoing maintenance issue within the reservoirs. Historically, the Corps has used dredging as the primary means of managing sediment that deposited in areas that interfere with man's use of the river. Most of these maintenance dredging actions have been conducted on a case-by-case basis without a long-term look at more effective ways of managing sediment. The Corps has now determined it would be more effective to evaluate sediment management within the lower Snake River on a watershed scale, and evaluate the potential for reducing sediment input, rather than focusing only on the reservoirs themselves. Although the Corps does not have the authority to manage land outside of the reservoir project boundaries, the Corps can identify and evaluate management strategies that could be implemented on non-Corps property.

The Corps has decided to develop a Programmatic Sediment Management Plan (PSMP) that will address sediment management within the four lower Snake River reservoirs and that portion of McNary reservoir contained within the lower Snake River. The plan will identify and evaluate ways the Corps can manage sediment within these reservoirs and examine the sediment input (sources) on a programmatic basis in the near-term, mid-term, and long-term. The intent of the PSMP is to identify ways to reduce the amount of sediment entering the reservoirs, identify how to manage the sediment once it enters the reservoirs, and identify possible changes to structures or operations to reduce maintenance and associated impacts while still providing for authorized project purposes, including navigation. The Corps intends to prepare an Environmental Impact Statement (EIS) for this plan and issued a Notice of Intent to prepare an EIS in the fall of 2005.

A variety of sediment management measures, which could be used individually or in combination, are under consideration by the Corps. Measures identified for evaluation in the Corps' Notice of Intent include:

Sediment Reduction Measures

Structural Sediment Reduction Measures

- Aquatic ecosystem restoration projects under current authorities (Section 206 Water Resources Development Act of 1996 and Section 1135 of the Water Resources Development Act of 1986)
- Shoreline vegetated filter strips
- Streambank erosion control

- Upstream sediment traps
- Improved logging road placement and design

Non-Structural Sediment Reduction Measures

- U.S. Natural Resource Conservation Service (NRCS) conservation programs
- Land use planning
- Public education
- Watershed planning
- Forest management practices
- Timber harvest planning

Sediment Management Measures

In-water systems to control sediment deposition

- Agitation to prevent settling
- Bendway weirs
- Dikes and dike fields
- Air curtains to prevent settling of material at specific locations

Sediment Removal and Management

- Agitation to re-suspend sediment
- Dredging to remove sediment
- Beneficial use of dredged material
- In-water disposal of dredged material
- Upland disposal of dredged material

System Management Measures

Modify Navigation System Infrastructure

- Relocate affected commercial navigation, recreational boating, and water intake facilities
- Build sediment retention dams upstream of Lower Granite Reservoir and/or in tributaries

Modify Reservoir Operations

- Raise pool levels to increase water depth
- Modify flows to flush sediment
- Draw down Lower Granite Reservoir to add flow conveyance capacity
- Provide flow conveyance at the confluence of the Snake and Clearwater Rivers

1.2 SCOPE AND OBJECTIVES

This report documents the first step in the effort towards evaluating management strategies on a watershed scale. Its purpose is to serve as an information base for subsequent analyses and planning efforts. It summarizes the results of an extensive investigation of available information sources related to sediment in the Lower Snake River Basin. The investigation covered generalized mapping of land ownership/stewardship responsibilities, identifying and documenting sediment management practices, identifying and documenting sediment data, and the collection and organization of geographic information system (GIS) data layers that are relevant to sediment within the basin. Specific objectives were to:

1. determine and pictorially document, through mapping, generalized land ownership/stewardship responsibilities within each basin;
2. determine and document any sediment management practices currently implemented by individual owner/steward by watershed;
3. determine and document any published or unpublished sediment data previously gathered within each watershed; and
4. collect and organize GIS data layers that have a potential effect on the contribution of sediment into the Lower Snake River and document in a summary report.

Although not part of the original objectives, the majority of the published and many unpublished documents were collected in electronic format. All electronic documents, indexes, and GIS layers were provided to the Corps on an external hard drive. Ten copies of the final report were also delivered.

1.3 STUDY AREA

The Lower Snake River Basin study area includes the Snake River Basin below Hells Canyon Dam to its confluence with the Columbia River [Hydrologic Unit Code (HUC) 1706]. The study area does not include areas upstream of Hells Canyon Dam, because the dam blocks any appreciable sediment transport from upstream areas. Also, because sediment transport from the North Fork Clearwater watershed is blocked by Dworshak Dam, this watershed is excluded from the current study area, leaving a study area of almost 33,000 square miles in size.

The study area is divided into five geographic areas. These are displayed in Figure 1 and include:

- Salmon River Subbasin
- Clearwater River Subbasin (exclusive of the North Fork Clearwater)
- Snake River Basin between Hells Canyon Dam and Clearwater River
- Grande Ronde Subbasin
- Lower Snake River Basin between Clearwater River and Mouth

Within each geographic area, information is summarized by 4th-field HUC or Cataloguing Unit. There are 26, 4th-field HUCs in the study area and they are referred to as watersheds in this report. Table 1 presents the area (in square miles), the percent of the study area, and number of 4th-field HUC watersheds in each geographic area.

Table 1. Size, Percent, and Number of 4th-Field HUC Watersheds within each Geographic Area making up the Study Area

Geographic Area	Number of 4th-Field HUC Watersheds	Area (Square Miles)	Percent of Study Area
Salmon Subbasin	10	13,994	43
Clearwater Subbasin (excluding North Fork)	6	6,907	21
Lower Snake River Basin – Hells Canyon Dam to Clearwater	3	2,104	6
Grande Ronde Subbasin	3	4,101	13
Lower Snake River Basin – Clearwater to Columbia	4	5,471	17
Total	**26**	**32,576**	**100%**

1.4 REPORT ORGANIZATION

Following this Introduction, Section 2.0 of this report provides a description of the methods used in the investigation. Section 3.0 describes the general land cover, ownership and stewardship of the basin along with a general description of sediment management practices associated with each owner type. Section 4.0 has two parts. The first part (Section 4.1) describes the overview studies on hydrologic and riparian disturbance and on erosion, mass wasting, and sedimentation, which are reported in two subsections of each geographic area discussion. The second part (Section 4.2) gives a broad overview of the sediment yield across the study area. Sections 5, 6, 7, 8, and 9 cover the five geographic areas and represent the main body of the report. As noted above, information is summarized by watershed (at the 4th-field HUC level) within each geographic area. Each of the sections is divided into five subsections. The first subsection describes "The Setting" of each geographic study area. As such, it summarizes the geography, topography, hydrology, land cover, land ownership, and land use of each geographic area. Next, is an overview of sediment trends and historic changes. These first two subsections attempt to establish the background or framework for the current situation in each geographic study area. The third subsection is called Sediment Sources and Yield, and summarizes general information on sediment production and transport issues within each watershed. The fourth subsection describes Management Practices and Restoration Projects within the geographic area and the final subsection provides preliminary highlights relative to sediment reduction opportunities within each geographic area. Section 10 presents preliminary recommendations for further study. Section 11 provides the references cited in this report.

The first three appendices (Appendices A, B, and C) also represent an important part of the documentation for this investigation. These appendices present abbreviated versions of the databases that represent the raw information and information sources identified in this investigation. Appendix A presents the References Database, Appendix B presents the GIS Layer Database, and Appendix C presents the Contact/Information Source Database.

The actual databases are in Excel spreadsheets, which accompany this report. The file names are as follows:

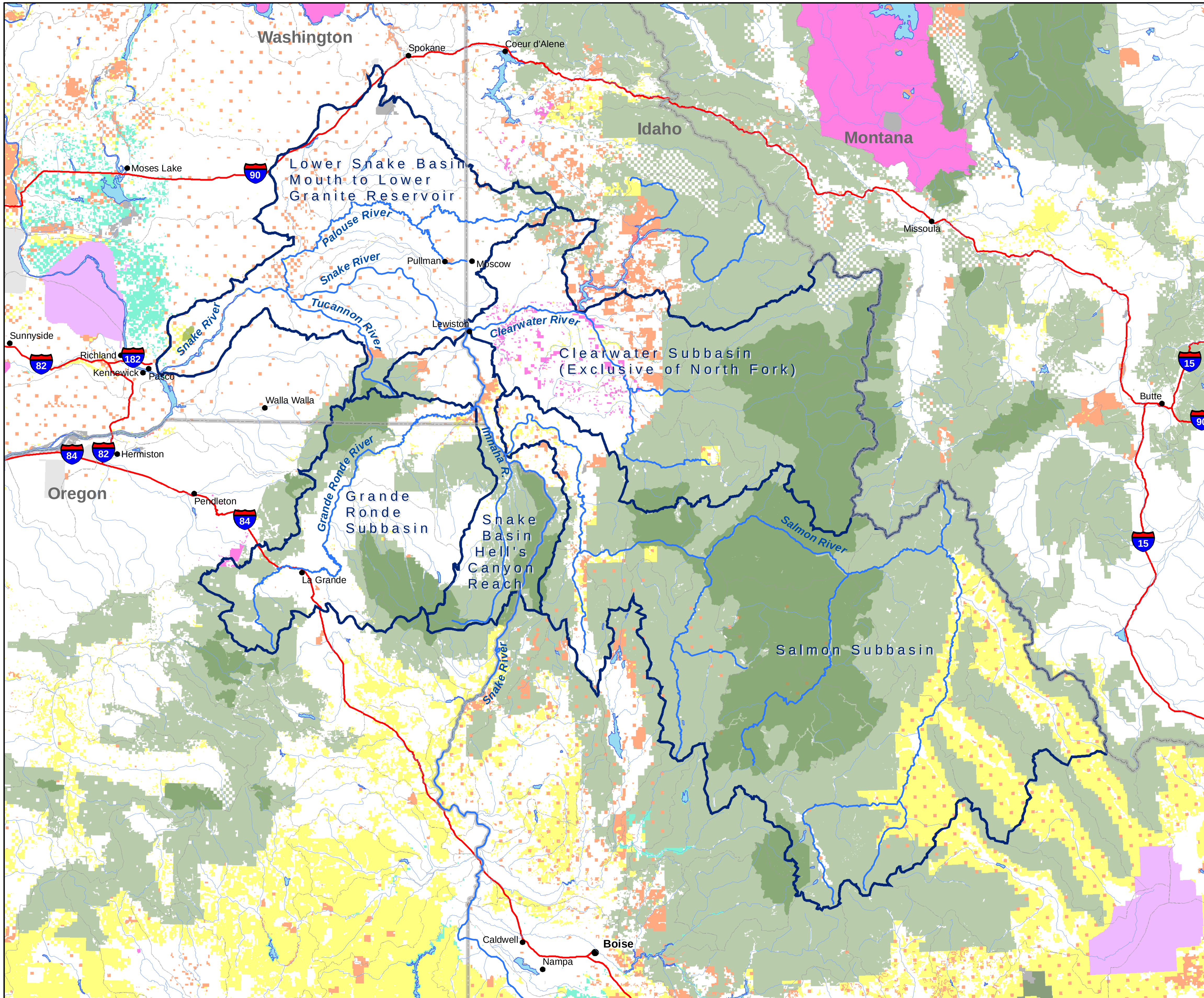
- References_Database_04-10-06.xls
- GIS_Layer_Database_04-10-06.xls
- Contact-Source_Database_04-10-06.xls

Appendix D presents an overview of studies on the transport and accumulation of sediment at the confluence of the Clearwater and Snake Rivers in the Lewiston-Clarkston area. Appendix E identifies the sources for information on the many dams and stream flow gauging (discharge monitoring) sites located within the three-state study area. This information will be important to consider in conducting subsequent phases of this sediment investigation.

Figure 1

Overview Map of Study Area Land Ownership

Lower Snake River Sediment Study



Legend

Land Ownership

- Forest Service
- Forest Service Wilderness
- Dept. of Defense
- Corps of Engineers
- Dept. of Energy
- Bureau of Land Managment
- Bureau of Reclamation
- USFWS / National Park Service
- State / City / County
- Tribal
- Private

- City
- Freeway System
- Stream
- State Boundary
- Geographic Area Boundary

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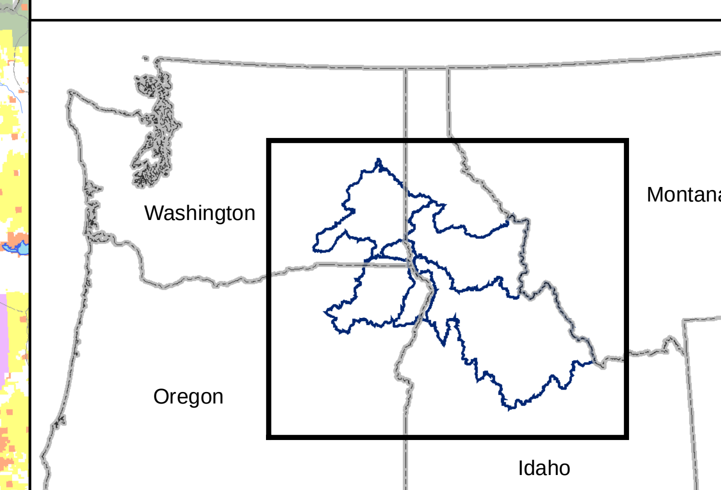

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2. METHODS

The primary efforts of this investigation involved the identification, collection, and documentation of references and GIS layers related to sediment in the Lower Snake River Basin. The work was conducted by a number of specialists simultaneously, so it was important that efforts be documented and shared among specialists, and that consistent procedures were followed. Therefore, the first step was the development of a study plan including procedures.

The next step was to search for, identify, and collect relevant information. This search was conducted by contacting relevant agencies and other professions and searching agency and other relevant Web sites to identify and collect available information. Relevant GIS layers were sought at the same time. Lists of potential relevant sources and potential topics to search for were identified prior to initiating the searches. All electronic documents collected were stored on a hard drive. Hard copy documents were stored in project files.

All sources investigated and information collected were documented in three spreadsheet databases. These include the following:

- References Database
- GIS Layer Database
- Contact/Information Source Database

A master spreadsheet for each database was maintained on a server. Each specialist working on the project worked on their own copy of each spreadsheet, and then added the new records to the master spreadsheets at the end of each day. The master spreadsheets were regularly backed up.

References Database

The purpose of this database is to document the information that was collected, including a reference number, the lead agency or organization that published or sponsored the reference, the complete bibliographic entry, the electronic file name or Web site where the document is located, a description of the document, a description of the sediment information in the document, notes, a relevance rating for each document, the author of the entry, and the 4th-field HUCs that are covered. All relevant references were recorded in the database. As a result, the database contains more than 500 references.

Appendix A contains an abbreviated version of the database. The entire database is in an Excel file that accompanies this report (References_Database_04-10-06.xls).

GIS Layer Database

The purpose of this database is to document the information that is contained in the GIS data layers collected, including a layer number, the lead agency or organization that published or distributed the layer, the title or subject of the layer, a description of the layer, the source of the layer (individual or Web site it was obtained from), the file name(s), the metadata file name, notes, the author of the entry, and the 4th-field HUCs that are covered. Specialists collected all potentially relevant GIS layers they could identify. The database contains over 150 GIS layers.

Appendix B contains an abbreviated version of the database. The entire database is in an Excel file that accompanies this report (GIS_Layer_Database_04-10-06.xls).

Contact/Information Source Database

The purpose of this database is to document who was contacted for information and which Web sites represent sources for information. The fields include: the agency or organization; the name, position, and phone number of individuals contacted; the Web site link for Web sites that represent sources of information; the date of contact (if a personal contact), the author of the entry, notes from the conversation or describing the Web site, and other notes. The database includes over 150 contacts and/or Web sites.

Appendix C contains an abbreviated version of the database. The entire database is in an Excel file that accompanies this report (Contact-Source_Database_04-10-06.xls).

3. GENERAL LAND COVER, OWNERSHIP, AND MANAGEMENT

3.1 LAND COVER

The study area is dominated by forest cover types in the higher elevations of the southeastern two-thirds of the study area (Table 2, Chart 1, and Figure 2). Overall, forest types make up 62 percent of the study area and agricultural/urban types make up 23 percent. The Salmon, Clearwater, and Grande Ronde geographic areas have at least 70 percent in forest types, while the Lower Snake River Basin – Hells Canyon Dam to Clearwater is 47 percent in forest types, and the Lower Snake River Basin – Clearwater to Columbia is less than 10 percent in forest types. The Salmon and the Clearwater geographic areas have the greatest percentage in mid and late-seral forests.

Agricultural/urban types dominate in the lower elevations of the northwestern one-third of the study area. The Lower Snake River Basin – Clearwater to Columbia has 79 percent in agricultural/urban types, while the Salmon geographic area has only 3 percent. The Clearwater, Lower Snake – Hells Canyon Dam to Clearwater, and the Grande Ronde areas are intermediate with 24, 22, and 17 percent, respectively.

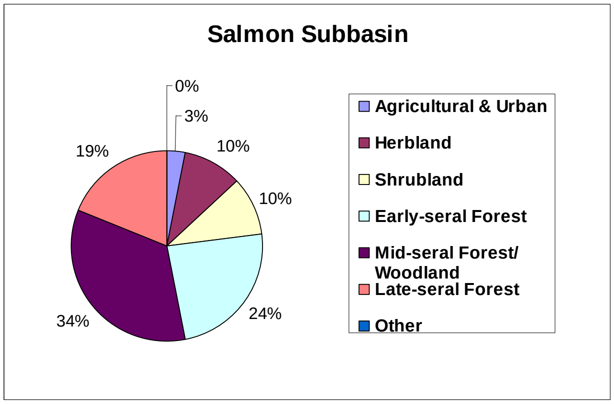
Table 2. General Land Cover by Geographic Area within the Lower Snake River Basin (percent of each geographic area and percent of total area)

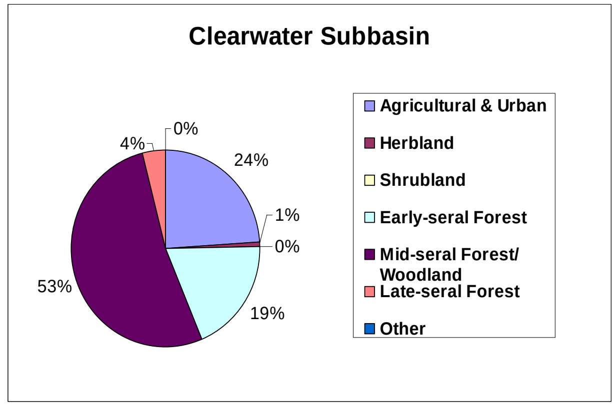
Geographic Area Name	Agricultural and Urban	Herbland	Shrubland	Early-seral Forest	Mid-seral Forest/ Woodland	Late-seral Forest	Other[1/]
Salmon Subbasin	3%	10%	10%	24%	34%	19%	0%
Clearwater Subbasin (excluding North Fork)	24%	1%	0%	19%	53%	4%	0%
Lower Snake River Basin – Hells Canyon Dam to Clearwater	22%	28%	2%	28%	13%	6%	1%
Grande Ronde Subbasin	17%	12%	0%	21%	41%	8%	1%
Lower Snake River Basin – Clearwater to Columbia	79%	4%	8%	1%	7%	0%	1%
Total Study Area	**23%**	**8%**	**6%**	**19%**	**33%**	**10%**	**1%**

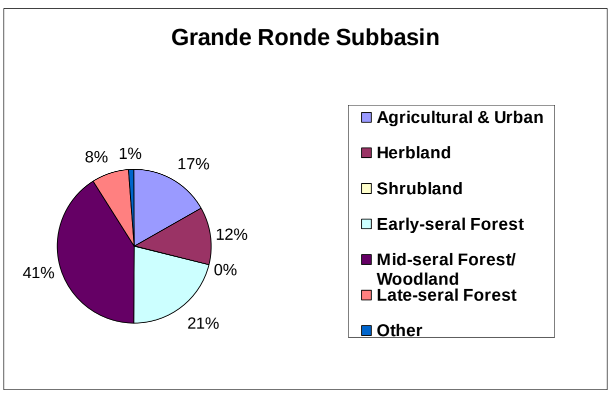
[1/] Riparian, Alpine, Water, Rock, Barren

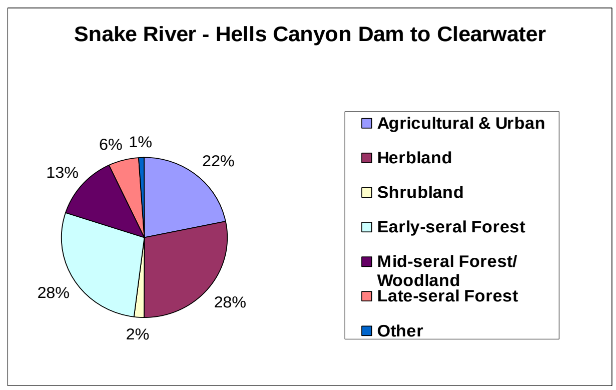
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

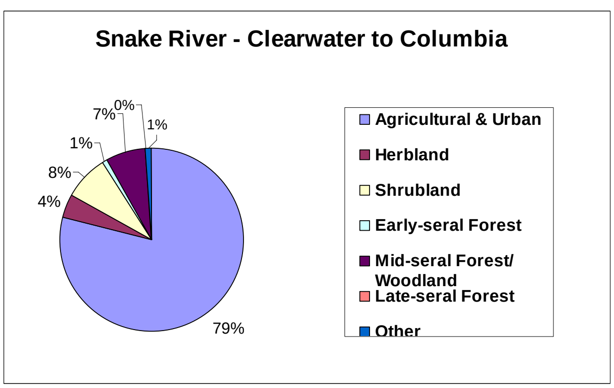
Chart 1. General Land Cover by Geographic Area within the Lower Snake River Basin (percent of each geographic area and percent of total area)











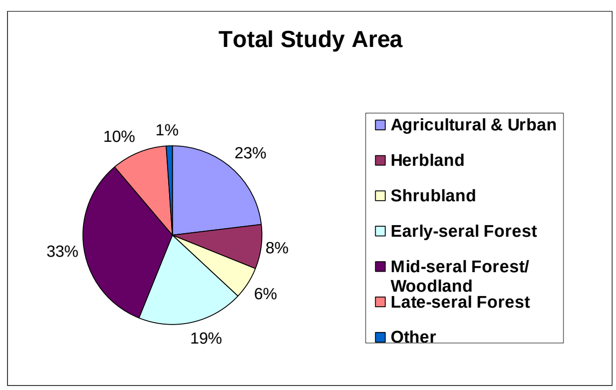
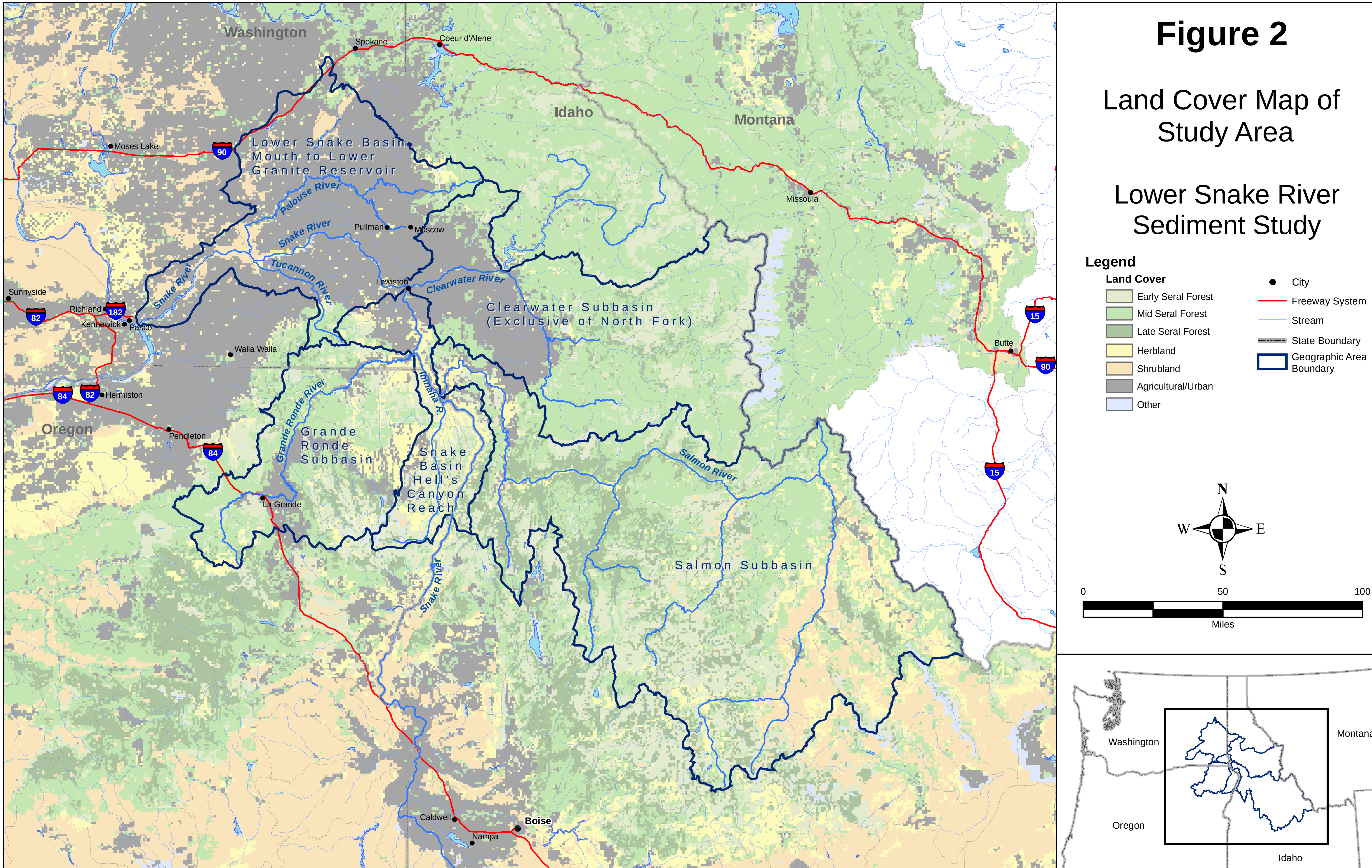


Figure 2

Land Cover Map of Study Area

Lower Snake River Sediment Study



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3.2 LAND OWNERSHIP

The USDA Forest Service (Forest Service) manages approximately 56 percent of the lands in the study area. Combined with the USDI Bureau of Land Management (BLM), the two agencies manage over 60 percent of study area lands (Table 3, Chart 2, and Figure 1). The individual geographic areas vary considerably in the proportion of their lands managed by these Federal agencies, ranging from less than 5 percent of the Snake River Basin downstream of the Clearwater to 90 percent of the lands in the Salmon subbasin.

Of note is the large amount of land managed by the Forest Service (primarily) and BLM that is in designated wilderness within the study area (21 percent of all lands).

The second largest category is private ownership, which represents 35 percent of the study area, and ranges from 9 percent of the Salmon subbasin to 92 percent of the Snake River Basin downstream of the Clearwater. Minor portions of the study area are owned by the states, counties, and cities (2 percent), tribes (<1 percent), and other Federal agencies (<1 percent). The other Federal agency lands consist mostly of lands managed by the Corps and U.S. Fish and Wildlife Service (USFWS).

Table 3. Land Ownership by Geographic Area within the Lower Snake River Basin (percent of each geographic area and percent of total area)

Geographic Area Name	Private	Tribal	State, County, and City	BLM (non-Wilderness)	National Forest (non-Wilderness)	National Forest and BLM Wilderness[1/]	Other Federal
Salmon Subbasin	9%	0%	1%	13%	50%	27%	<1%
Clearwater Subbasin (excluding North Fork)	33%	1%	3%	1%	33%	29%	<1%
Lower Snake River Basin – Hells Canyon Dam to Clearwater	40%	0%	3%	1%	38%	18%	0%
Grande Ronde Subbasin	51%	<1%	0%	1%	32%	16%	0%
Lower Snake River Basin – Clearwater to Columbia	92%	0%	3%	<1%	3%	1%	<1%
Total Study Area	**35%**	**<1%**	**2%**	**6%**	**35%**	**21%**	**<1%**

[1/] The vast majority of the wilderness acres are on National Forest System lands; only 6,000 acres (Juniper Dunes) are under BLM management in the Snake River Basin – Clearwater to Columbia geographic area.

Chart 2. Land Ownership by Geographic Area within the Lower Snake River Basin (percent of each geographic area and percent of total area)

3.3 LAND MANAGEMENT

Sediment management practices within the Lower Snake River Basin vary with the landowner and the management plan they implement. This section provides a general overview of management practices related to sediment for the major Federal, state, and other landowners in the study area.

3.3.1 Federal Land Management

As noted in Section 3.1, the Forest Service and BLM are the primary Federal land managers in the study area. National Forest System lands are managed under Land and Resource Management Plans (or Forest Plans), which guide all natural resource management activities, establish Forest-wide multiple use goals and objectives, and establish standards and guidelines for National Forest management. BLM lands are managed under similar plans called Resource Management Plans.

These Federal lands can be broadly divided into those lands inside designated wilderness and those outside of wilderness. Wilderness makes up 21 percent of the study area (Table 3). However, the proportion of each geographic area made up of wilderness varies considerably, ranging from 1 percent of the Snake River Basin downstream of the Clearwater to 29 percent of the Clearwater subbasin (excluding the North Fork). Management of lands designated as wilderness is extremely restrictive. In general, wilderness is managed to maintain a natural state, within which only natural disturbance events are allowed to proceed. Therefore, human-caused ground-disturbing activities are not allowed (including sediment management or restoration activities).

About 41 percent of study area lands are managed by the Forest Service and BLM outside of wilderness. These lands are allocated to a variety of management prescriptions and are managed under a range of standards and guidelines. However, substantial consistency in riparian standards and guidelines was added to all Forest Service and BLM-managed lands in the Columbia River Basin because of plan amendments adopted in the mid-1990s. These amendments were adopted as interim management strategies with the objective of producing a consistent level of additional protection to riparian areas and improvements in water quality. They are referred to as PACFISH (USDA Forest Service and USDI BLM 1994) and INFISH (Inland Native Fish Strategy, Forest Service 1995). PACFISH guidelines are used in anadromous fish areas east of the Cascade Crest. INFISH guidelines are used for protection of habitat and populations of resident fishes outside of anadromous fish habitat. PACFISH (anadromous fish habitat) and INFISH (non-anadromous) established Riparian Goals and Riparian Management Objectives (RMOs). Riparian Goals were written to maintain or restore water quality, stream channel integrity, instream flows to support healthy habitats, natural timing and variability of the water table elevation in meadows and wetlands, diversity of plants, riparian vegetation, and appropriate habitats. The RMOs (objectives) for stream channel conditions provide criteria to measure attainment of goals of healthy, functioning watershed, riparian areas, and fish habitats. Included are objectives for habitat features such as pool frequency, water temperature, large woody debris, and bank stability, bank angle.

Riparian Habitat Conservation Areas (RHCAs) were established adjacent to all stream courses and adjacent waters to provide areas where management activities are limited in order to protect the stream habitat. RHCA widths range from 50 feet on intermittent streams to 300 feet on fish-bearing streams. Altogether, four categories of RHCAs are defined: fish-bearing streams; permanently flowing non-fish bearing streams; ponds, lakes, and wetlands greater than 1 acre; and intermittent streams, wetlands less than 1 acre, landslides, and landslide-prone areas. Project and site-specific standards and guidelines are listed in PACFISH and INFISH that apply to all RHCAs and projects and activities outside RHCAs that would degrade the riparian area. The standards and guidelines modify timber harvest, grazing, recreation and other activities. They include the following: timber harvest is prohibited with a few exceptions; new road building is to be minimized in RCHAs and roads that are already present are to be managed to reach RMOs; grazing is to be adjusted or eliminated to prevent impacts inconsistent with attaining RMOs. Deviation from the defined RHCA definitions and standards and guidelines requires project-specific consultation with the National Marine Fisheries Service (NMFS) and USFWS. The details for the goals, RMOs, RHCA definitions, and the standards and guidelines are in Appendix C under Alternative 4 of the Environmental Assessment portion of PACFISH (USDA Forest Service and USDI BLM 1995). For INFISH, the details for the RMOs and RHCAs are in Appendix E under Alternative D of the Environmental Assessment portion of INFISH (USDA Forest Service 1995).

PACFISH and INFISH provide management direction on Federal lands until the individual Forest Plans and Resource Management Plans are revised to provide the same habitat protection (USDA Forest Service and USDI BLM 1995; USDA Forest Service 1995).

In addition to riparian standards and guidelines, each Forest Plan and Resource Management Plan identifies Best Management Practices (BMPs) and other measures to follow that relate to limiting sediment delivery to streams. These practices and measures relate to timber harvest, road construction, grazing, and other potentially ground-disturbing activities.

3.3.2 State, County, and City Land Management

The study area includes substantial areas within Washington, Oregon, and Idaho. The management of state lands naturally varies by state; however, the majority of state lands in all three states are managed for fish and wildlife habitat, grazing, and/or forest management. All three states have a State Forest Practices Act, which guides logging, road-building and other activities on state forest lands. Guidelines are intended to protect fish-bearing streams and limit sediment delivery. Washington's Forest Practices Rules are the most protective. County and city lands make up a very small proportion of study area lands.

3.3.3 Tribal Land Management

The only tribe that manages a significant acreage of lands within the study area is the Nez Perce Tribe. The Tribe has a number of departments and divisions responsible for protecting, enhancing, and restoring tribal resources both on the reservation and within the Tribe's treaty territory. Reservation lands are managed for fish and wildlife, agriculture and grazing, forestry, and other activities.

3.3.4 Private Land Management

Private lands within the study area are managed for a variety of uses. The dominant uses include agriculture, grazing, and forestry. A myriad of state and local laws affect the management of private lands, but not substantially. The State Forest Practices Acts may be the most restrictive in terms of limiting activities that affect sediment on a large scale. Numerous Federal, state, and local programs assist in the conservation and restoration of private lands. These are discussed in Section 3.4

3.4 CONSERVATION AND RESTORATION PROGRAMS AND LEGISLATION

A wide variety of Federal, state, and local programs are being implemented across the study area that affect sediment and are designed to protect, conserve, or restore fish or wildlife habitats or water quality. These programs often apply to all ownerships, but participation is voluntary for private ownerships. This section presents an overview of the major programs that affect sediment. Table 4 provides an overview of the major regulations or programs that involve sediment input to streams in the study area. In addition to these, there are many other specific regulations and laws that are implemented at the state, county, and local levels. Examples would include BMPs for road construction and maintenance, zoning ordinances, shoreline management restrictions, and others.

Table 4. Major Federal, State, and Other Programs and Legislation affecting Sediment Production and Control

Regulation/Program	Administering Agency	Description/Notes
Clean Water Act (CWA) – State Water Quality Standards	Washington Department of Ecology (WDOE), Oregon Department of Environmental Quality (ODEQ), Idaho Department of Environmental Quality (IDEQ)	States establish water quality standards that define the goals and limits for all waters within their jurisdictions. In establishing water quality standards, states must take three major, interrelated actions. They must 1) designate uses; 2) establish water quality criteria; and 3) develop and implement antidegradation policies and procedures. U.S. Environmental Protection Agency (EPA) oversees the states' administration of the Clean Water Act.
Clean Water Act - Section 303(d)	WDOE, ODEQ, and IDEQ	States identify polluted water bodies and set priorities for clean up. The "impaired waters" list is referred to as the 303(d) listed streams. States must develop a watershed restoration action plan, called a Total Maximum Daily Load (TMDL) Plan, for 303(d) listed waters. After plans are developed, implementation and monitoring must begin.
Clean Water Act - Section 404	U.S. Army Corps of Engineers (Corps)	Protect aquatic life and water resources; requires a permit when locating a structure, excavating, or discharging dredged or fill material in waters of the United States.
Section 10 – Rivers and Harbors Act of 1899	Corps	Protect aquatic life and water resources; requires a permit when locating a structure, excavating, or discharging dredged or fill material in waters of the United States.
Bonneville Project Act of 1937, as amended	Bonneville Power Administration (BPA)	Has mitigation responsibility for fish and wildlife restoration under the Fish and Wildlife Program of the Northwest Power and Conservation Council (NPPC). Provides planning, regulatory compliance, and oversight for fish and wildlife mitigation efforts in the Columbia River Basin that are developed under the NPPC's Fish and Wildlife Program.
Federal Power Act of 1930, as amended	Federal Energy Regulatory Commission (FERC)	Includes multiple permits, agreements, and other requirements under the license.
Endangered Species Act of 1973, as amended (ESA)	National Marine Fisheries Service (Anadromous Fish)/U.S. Fish and Wildlife Service (Wildlife and resident fish)	Protect, mitigate, and enhance listed species from actions that may result in harm or death to the species.
Fish and Wildlife Coordination Act of 1936, as amended	National Marine Fisheries Service (Anadromous Fish)/U.S. Fish and Wildlife Service (Wildlife and Resident Fish)	Coordinate and provide consultation with lead entities on the review of proposed Federal projects and their potential effect on anadromous fish species.

Table 4 (continued). Major Federal, State, and Other Programs and Legislation Affecting Sediment Production and Control

Regulation/Program	Administering Agency	Description/Notes
Magnuson-Stevens Fishery Conservation and Management Act (Essential Fish Habitat) of 1976, as amended and re-authorized	National Marine Fisheries Service	Review and provide opinions on activities that may affect Essential Fish Habitat, as defined by the Magnuson-Stevens Act.
Multiple USDA Programs	USDA Natural Resource Conservation Service and Farm Service Agency Programs	Many different programs (often voluntary) that preserve or restore croplands, wetlands, water quality, and fish and wildlife habitats through BMPs, reserves, incentives, and funding. Includes multiple authorizations (see Table 5).
Forest Practices Act of 1971 (Oregon)	Oregon State Department of Forestry	Governs forest practices on all non-Federal lands.
Forest Practices Act of 1974 (Washington)	Washington Department of Natural Resource	Governs forest practices on all non-Federal lands.
Forest Practices Act of 1974 (Idaho)	Idaho Department of Lands	Governs forest practices on all non-Federal lands.
Multiple State and Local Programs and Permits	Multiple Agencies	Examples include: • Hydraulic Project Approval (Washington) • Shoreline Substantial Development, Conditional Use, Variance Permit or Exemption – Local Government • Local Planning Certification (Oregon) • Floodplain Management Permit and/or Critical Areas Ordinances – review by Local Government • Section 401 (Clean Water Act) Water Quality Certification – from WDOE, IDEQ, or ODEQ • Washington Aquatic Resources Use Authorization Notification (if project is on, crosses, or impacts the bedlands, tidelands, or shorelands of a navigable river)
Sovereign Nation Status	Native American Tribes – Nez Perce Tribe has the largest land-holding in the study area.	Provides management authority for lands within reservation lands.

3.4.1 Bonneville Power Administration and the Northwest Power and Conservation Council Programs

The Northwest Power and Conservation Council (NPCC) was directed by the Northwest Power Act of 1980 to develop a program – the Columbia River Basin Fish and Wildlife Program – to protect, mitigate, and enhance fish and wildlife communities and populations affected by the Federal Columbia River hydropower system. The NPCC was also directed to make annual funding recommendations to the Bonneville Power Administration (BPA) for projects to implement the program. Subbasin plans have been developed to help guide the review, selection, and funding of projects that implement the NPCC's Columbia River Basin Fish and Wildlife Program. As of 2005, all 40 subbasin plans have been approved for the Columbia River basin. The eight subbasin plans that cover the study area include the following:

- Salmon Subbasin Plan
- Clearwater Subbasin Plan
- Snake Hells Canyon Subbasin Plan
- Imnaha Subbasin Plan
- Grande Ronde Subbasin Plan
- Palouse Subbasin Plan
- Tucannon Subbasin Plan
- Lower Snake Subbasin Plan

Habitat improvement and watershed project expenditures through the program since 1982 have totaled more than $450 million for the entire Columbia River basin. These projects are varied, but many have a direct influence on sediment. Examples of these include revegetation and/or fencing of riparian areas, land purchase or easements to protect fish and wildlife habitats, and recontouring or reconstruction of stream banks and channels.

Funds are distributed to a wide variety of entities such as Federal, state, and local agencies, Native American Tribes, and others. The following Web sites provide examples of recent projects (2001 through 2004) that have received funding in the Blue Mountain Province, Columbia Plateau Province, and Mountain Snake Province:

http://www.cbfwa.org/FWProgram/Reports/FY2004/Chapter03BlueMountain.pdf

http://www.cbfwa.org/FWProgram/Reports/FY2004/Chapter07ColumbiaPlateau.pdf

http://www.cbfwa.org/FWProgram/Reports/FY2004/Chapter12MountainSnake.pdf

The 542 projects currently under review for FY2007 – 2009 funding are listed on the following Web site:

http://www.nwcouncil.org/fw/budget/2007/Default.asp

This site includes summary reports by province, province prioritization, the review guidance document, reviews by state, a mainstem/systemwide review, and a general process schedule.

3.4.2 USDA Natural Resource Conservation Service and Farm Service Agency Programs

Within the USDA, the NRCS and the Farm Service Agency oversee the implementation of conservation programs to help solve natural resource concerns on private agricultural and forestry lands (Table 5). The NRCS administers the Environmental Quality Incentives Program (EQIP), which was established in the 1996 Farm Bill and provides a voluntary conservation program for farmers and ranchers who face serious threats to soil, water, and related natural resources. The Conservation Reserve Program (CRP) and the Continuous Conservation Reserve Program (CCRP) are protection programs implemented on croplands and riparian areas, respectively. These two programs are managed by the Farm Service Agency with technical assistance provided by the NRCS. The Conservation Reserve Enhancement Program (CREP) helps to establish forested riparian buffers. The NRCS assists landowners to develop farm conservation plans and provides engineering and other support for habitat protection and restoration [Public Law (PL) 566]. Other NRCS programs include River Basin Studies, Forestry Incentive Program, Wildlife Habitat Incentives Program (WHIP), and the Wetlands Reserve Program (WRP). A summary of the major NRCS and Farm Service Agency programs that affect sediment production or related issues is provided in Table 5.

3.4.3 U.S. Environmental Protection Agency Programs

The U.S. Environmental Protection Agency (EPA) is responsible for implementing and administering the Clean Water Act (CWA), which requires enforcement of water quality standards by states. These standards are separated into point and nonpoint source water pollution, with point sources requiring permitting under the CWA. This segregation means that most farming, ranching, and forestry practices are considered nonpoint sources and thus do not require permitting by EPA. A TMDL, or total maximum daily load, is a tool for implementing water quality standards where impairment of beneficial uses exists. TMDL assessments must be completed on 303(d) listed streams. The EPA provides funding through Section 319 of the CWA for TMDL implementation projects. The Washington Department of Ecology (WDOE), Oregon Department of Environmental Quality (ODEQ), and the Idaho Department of Environmental Quality (IDEQ) administer the programs in the respective states.

Table 5. Major NRCS and Farm Service Agency Programs that Involve Sediment or Related Issues

Program	Purpose	Additional information
Conservation Reserve Program (CRP)	Remove highly erodible land from agricultural production and planting cover crops to increase wildlife habitat	Voluntary program for private landowners involving a 10-year contract and installation and annual payments
Continuous Conservation Reserve Program (CCRP)	Restore riparian habitat and improve water quality	Voluntary program for private landowners involving a 10-15 year contract and installation and annual payments
Conservation Reserve Enhancement Program (CREP)	Protect and restore agricultural land and riparian habitat by removing land from production	Voluntary program for private landowners involving a 10-15 year contract, rent, incentive and maintenance payments, and cost-sharing for installation
Wildlife Habitat Incentives Program (WHIP)	Restore and enhance fish and wildlife habitat on private lands	Voluntary program for private landowners; includes both financial and technical assistance from NRCS
Wetland Reserve Program (WRP)	Restore, create, protect, and enhance wetlands	Voluntary program for private landowners, who may participate in restoration cost-sharing or establish conservation easements on their land
Environmental Quality Incentives Program (EQIP)	Address soil, water, and related natural resource concerns on private lands in an environmentally beneficial and cost-effective manner	Voluntary program targeting farmers and ranchers; technical and financial assistance provided by NRCS, esp. for implementing land management practices such as nutrient management, pest management, and grazing land management
The Public Law 566 Small Watershed Program (PL 566)	Improve watershed conditions	Local organizations can seek funding from NRCS and other Federal, state, and local funds

Source: *Lower Snake Mainstem Subbasin Plan* (Pomeroy Conservation District 2004)

3.4.4 U.S. Army Corps of Engineers

Environmental restoration is one of the missions of the Corps. Following completion of a feasibility study and design of the project, the Corps will share 65 to 75 percent of the cost of project construction. Section 1135 of the Water Resources Development Act provides the Corps the authority to modify existing Corps projects to restore habitat. Section 206 of the Act permits the Corps to restore degraded aquatic ecosystems, regardless of the presence of a Corps project.

3.4.5 National Marine Fisheries Service

The NMFS administers the Pacific Coastal Salmon Recovery Fund (PCSRF). This fund was established in 2000 to provide grants to the states and tribes to assist state, tribal and local salmon conservation and recovery efforts. The PCSRF was requested by the governors of the states of Washington, Oregon, California and Alaska in response to listings of West Coast salmon and steelhead populations under the Endangered Species Act of 1973 (ESA). The fund supplements existing state, tribal, and local programs to foster development of Federal-state-tribal-local partnerships in salmon and steelhead recovery and conservation. Throughout the Pacific Northwest, Alaska, and California, there are hundreds of habitat restoration projects that have been funded. The following website provides further information on the PCSRF and projects funded through this organization:

http://webapps.nwfsc.noaa.gov/servlet/page?_pageid=784&_dad=portal30&_schema=PORTAL30

The PCSRF provides these funds to other organizations. Most prominent in the study area are the:

- Washington State Interagency Committee (IAC) Salmon Recovery Funding Board (SRFB) – see website:

  http://www.iac.wa.gov/maps/presentation/map.asp?ScreenWidth=1024&MapType=2a&Cmd=INIT&AreaType=County&Area=ALL

- Oregon Watershed Enhancement Board (OWEB) – see website:

  http://www.oregon.gov/OWEB/docs/pubs/BiennialReport1_2003-2005.pdf

- Idaho Office of Species Conservation – see website:

  http://osc.idaho.gov/strategic_plan.html

4. GENERAL SEDIMENT SOURCE AND YIELD INFORMATION

This section has two parts. The first part (Section 4.1) describes the studies that are reported in each geographic area discussion under two different subsections. The second part (Section 4.2) gives a broad overview of the sediment yield across the study area.

4.1 OVERVIEW STUDIES ON HYDROLOGIC AND RIPARIAN DISTURBANCE, EROSION, MASS WASTING, AND SEDIMENTATION

A number of studies have developed ratings and other results across the entire Columbia River Basin or larger areas. These studies are useful because they give perspective and permit relative comparisons to be made among geographic areas and among watersheds within geographic areas. The ratings and other results are presented for each geographic area in Sections 5 through 9 under subsections titled: *Overview of Sediment Trends and Historic Change* and *Overview Studies on Erosion, Mass Wasting, and Sedimentation*. This section presents a description of these overview studies.

ICBEMP Ratings for Overall Level of Hydrologic and Riparian Disturbance

The Interior Columbia Basin Ecosystem Management Project (ICBEMP) conducted by the Forest Service and the BLM (Quigley and Arbelbide 1997) developed many ratings for each watershed in the Columbia Basin relative to other watersheds. In the *Overview of Sediment Trends and Historic Change* subsections of Sections 5 through 9, three ratings are given for the overall level of hydrologic and riparian disturbance within each watershed. These ratings are described as follows:

- Relative Hydrologic Disturbance Rating of Forest Environments: This rating was based on four impact variables – surface mining, dams, cropland conversion, and roads. Each 6th-field HUC was assigned to an impacted or non-impacted class for each of the four impact variables and the percent of impacted 6th-field HUCs within each 4th-field HUC watershed was calculated by impact variable type. The four impact variable percent values for each watershed were then converted to cumulative frequency distributions and a generalized description of hydrologic disturbance was developed by summing all four impact variable values for forest land within each 4th-field HUC. These cumulative frequency values were converted to three hydrologic disturbance class ratings: low = 0 to 33 percent, moderate = 34 to 66 percent, and high = greater than 66 percent.

- Relative Hydrologic Disturbance Rating of Rangeland Environments: This rating is exactly the same as the one described above for forest environments, except this one covers rangeland habitats.

- Relative Riparian Disturbance Rating of Rangeland Environments: This rating was based on estimated riparian disturbance levels based on information concerning the sensitivity of streambanks to grazing and the sensitivity of stream channel function to the maintenance of riparian vegetation. In this approach, the resiliency of riparian areas to grazing was used to infer probable riparian area disturbance given the fact that many riparian areas in the Columbia Basin have experienced historically high grazing pressure which often still persists today. Accordingly, areas with low relative grazing resiliency were considered to potentially have high riparian disturbance while areas with relatively high grazing resiliency were considered to potentially have lower riparian disturbance. Cumulative frequency distributions were calculated for the combined streambank sensitivity and riparian vegetation sensitivity scores of each rangeland 6th-field HUC which were then averaged by watershed (4th-field HUC). Stratification into classes was done the same way as for the Hydrologic Disturbance Ratings described above.

ICBEMP Ratings for Soil Erosion, Mass Failure, and Sediment Hazard from Nonpoint Sources

The ICBEMP also developed various soil erosion, mass failure, and sediment hazard ratings for nonpoint sources for each watershed, relative to all Columbia Basin watersheds (Quigley and Arbelbide 1997). In the *Overview Studies on Erosion, Mass Wasting, and Sedimentation* subsections of Sections 5 through 9, seven ratings are given for each watershed. These ratings were developed following general procedures described in EPA (1980) with required modification to facilitate use of general erosion/sediment process models at broader spatial scales (Quigley and Arbelbide 1997).

In all cases, the ratings were converted to a cumulative frequency distribution percentile, which expressed the percent of other watersheds within the Columbia Basin that had the same or smaller value for the interpretation. Maps were then produced with each watershed assigned to one of four classes based on their cumulative frequency numbers as follows: low (0-25), low to moderate (26-50), moderate to high (51-75), and high (76-100). The ratings are described below:

- Surface Soil Erosion Hazard: This rating was developed using an approach similar to the EPAs Modified Universal Soil Loss Equation (MUSLE). In this model (EPA 1980), surface soil erosion in tons per acre per year was estimated based on slope/length, soil erodibility, rainfall intensity, and vegetation management (cover). The version of the model based on existing vegetation cover was used in this report.

- Earth Flow Hazard: This rating used similar parameters and approaches to those identified in surface soil erosion hazard analysis (above); however, parameter weights were adjusted to follow suggested procedures (EPA 1980). Specific parameters used were slope, probable soil texture and permeability, and average annual precipitation.

- Debris Avalanche Hazard: This rating used similar parameters and approaches to those identified in surface soil erosion hazard analysis (above); however, parameter weights were adjusted to follow suggested procedures (EPA 1980). Specific parameters used were slope and average annual precipitation.
- Sediment Delivery Potential: This rating was calculated by: 1) overlaying the 1:100,000 scale hydrography map onto each watershed delineation and calculating drainage density, 2) calculating the average slope of each delineation with 90-meter DEM data, and 3) multiplying drainage density by the average slope of each delineation to obtain its initial sediment delivery index.
- Sediment Delivery Hazard: This rating was developed by multiplying the relative sediment delivery potential scores by the average surface soil erosion hazard value for a watershed.
- Road Erosion Hazard: This rating was calculated for each watershed based on groupings of lithology and their relative erosion rates following road construction.
- Road Sediment Delivery Hazard: This rating was developed by multiplying the relative sediment delivery potential scores by the average road erosion hazard value for a watershed.

NMFS Draft Erosion Rate Model Outputs

NMFS (Baker et al. 2005) has developed two draft models for estimating increases in erosion rates relative to historical rates in the Interior Columbia Basin, to assist in the assessment of the level of salmonid population impact from excessive fine-sediment deposition. The first model predicts change in surface erosion rates in historically non-forested areas based on slope, soil erosivity, and land use factors. The second model predicts change in erosion rates due to mass wasting and surface erosion from roads and clear cuts in currently forested areas. In historically non-forested areas, a simplified variant of the Revised Universal Soil Loss Equation (RUSLE) was developed for estimating the impact of land use on erosion rates (Renard et al. 1996). In historically forested areas, a second empirical model was developed to account for mass wasting based on a simple classification of hillslope angle and land use classification. Both models are designed to produce erosion rate indices that are estimates of how much erosion has increased over natural levels.

U.S. Geological Survey Landslide Hazard Mapping

The U.S. Geological Survey (USGS) developed a landslide overview map (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas that are susceptible to landsliding in the conterminous United States. It was developed by evaluating the geologic map of the United States and classifying the geologic units according to high, medium, or low landslide incidence (number) and high, medium, or low susceptibility to landsliding.

NRCS Cropland Erosion Maps

A NRCS analysis of cropland for 1997 in the conterminous United States, referred to as the 1997 Natural Resources Inventory (NRCS 2000) provides a number of maps related to cropland erosion. One is called "Excessive Erosion on Cropland, 1997." This map is a dot density map showing acres where excessive erosion from wind and water is occurring on cropland. It shows the acres of highly erodible land eroding excessively and the acres of non-highly erodible land eroding excessively, in 5,000 acre units. Excessive erosion is defined as erosion greater than the tolerable rate (the maximum rate of annual soil erosion that will permit crop productivity to be sustained economically and indefinitely). Highly erodible land is defined as land where the erodibility index is greater than or equal to 8. The Universal Soil Loss Equation (USLE) is used to calculate water erosion and the Average Annual Wind Erosion Equation is used to calculate wind erosion.

4.2 OVERVIEW OF SEDIMENT DELIVERY TO THE SNAKE RESERVOIRS

The delivery of sediment to Lower Granite and the other three Lower Snake River reservoirs is an extremely complex interaction of numerous processes and physical conditions. Because of the size of the area, there is a high level of spatial and temporal variability among sources. Assembling the information in this report, including the supporting GIS product, is an important first step in developing the information and analyses necessary to evaluate the feasibility of sediment management activities in reducing the need for dredging on the Lower Snake. This section provides some general information concerning the magnitude and distribution of sediment sources based on information in the literature. An overview of the studies on transport and accumulation of sediment at the confluence of the Clearwater and Snake Rivers in the Lewiston-Clarkston area is presented in Appendix D.

The study area is divided into five geographic areas. Based on Table 1, the sediment contributing drainage area associated with each area is:

Salmon Subbasin	13,994 square miles
Clearwater Subbasin (excluding North Fork)	6,907 square miles
Lower Snake River Basin – Hells Canyon Dam to Mouth of Clearwater	2,104 square miles
Grande Ronde Subbasin	4,101 square miles
Lower Snake River Basin – Clearwater River to Mouth	5,471 square miles
TOTAL	**32,576 square miles**

These areas represent sediment “contributing” portions of the watershed. Therefore, areas upstream of major dams such as Dworshak on the North Fork of the Clearwater and Hells Canyon Dam on the Snake were excluded. The entire drainage area of the Snake River above Ice Harbor Dam is 108,800 square miles. Based on these numbers, there are 75,750 square miles of drainage area that is considered to not contribute sediment because it is trapped in large dams. The vast majority of the noncontributing area, 73,300 square miles, is on the Snake River above Hells Canyon. This area represents nearly 70 percent of the entire Snake River Basin.

Of the contributing area, the Salmon, Clearwater and Grande Ronde Rivers and the remaining portions of the Snake River below Hells Canyon Dam and above the confluence with the Clearwater, total 27,106 square miles and represent 83 percent of the sediment-contributing area.

4.2.1 USGS Studies

A study of the sediment load from this area was conducted from 1972 through 1979 by the USGS (Jones and Seitz 1980). In this study, the USGS measured both suspended and bedload on the Snake River near Anatone, Washington and on the Clearwater at Spalding, Idaho. Rating curves were developed from the measurements and daily sediment loads calculated based on application of the sediment rating curves. Table 6 provides a summary of the results of the USGS study. The Snake River near Anatone, Washington includes the Salmon, Grande Ronde and all but the lower 25 miles of the remaining Snake River drainage area between Hells Canyon Dam and the Clearwater confluence. The Clearwater gage is about 10 miles upstream of the Snake River confluence. Therefore, the sum of the sediment loads at these two gages closely represents the total sediment load delivered to Lower Granite Reservoir from the Snake River above Lewiston.

Though this is a limited period of record, some inferences about sediment delivery to Lower Granite Reservoir can be made from this information. First, the majority of the material delivered is suspended load. It comprises approximately 95 percent of the total load on the average. The Snake River delivers more sediment than the Clearwater River with an average ratio of nearly four times or 80 percent of the sediment from the Snake and 20 percent from the Clearwater. Though this ratio varies from year to year, the dominance of the Snake River is apparent in all but the extreme drought year of 1977 when both systems delivered negligible sediment (less than 3 percent of the average for the period). This also points out the high variability in the annual delivery of sediment. Looking at the four highest years of 1972, 1974, 1975 and 1976, they represent nearly 90 percent of the sediment delivered during the 9-year period, though they represent less than half the time period. The highest year, 1974, is responsible for delivering 37 percent of the sediment accounted for over the 9 years of the study, or slightly over three times the average annual load.

Table 6. Summary of Sediment Transport in Millions of Tons per Year on the Snake and Clearwater Rivers near Lewiston, Idaho

Year	Snake near Anatone, WA			Clearwater at Spalding, ID			Combined		
	Susp	Bed	Total	Susp	Bed	Total	Susp	Bed	Total
1972	2.85	0.19	3.04	0.92	0.04	0.96	3.77	0.23	4.00
1973	0.24	0.01	0.25	0.03	0.00	0.03	0.27	0.01	0.28
1974	5.29	0.23	5.52	1.28	0.05	1.33	6.57	0.28	6.85
1975	2.10	0.15	2.25	0.45	0.03	0.48	2.55	0.18	2.73
1976	2.18	0.15	2.33	0.42	0.03	0.45	2.60	0.18	2.78
1977	0.03	0.00	0.03	0.03	0.00	0.03	0.06	0.00	0.06
1978	0.97	0.09	1.06	0.26	0.01	0.27	1.23	0.10	1.33
1979	0.42	0.03	0.45	0.20	0.01	0.21	0.62	0.04	0.66
Total	14.08	0.85	14.93	3.59	0.17	3.76	17.67	1.02	18.69
Average	**1.76**	**0.11**	**1.87**	**0.45**	**0.02**	**0.47**	**2.21**	**0.13**	**2.34**

Source: Modified from Jones and Seitz (1980)

The size distribution of sediment transported was provided for both bedload and suspended load. However, no attempt was made to identify the overall breakdown of sediment sizes transported over the 9-year study period. As a general representation of sediment sizes transported, the study discusses this information for 1979. In 1979 on the Snake River, 92 percent of the suspended sediment was finer than sand (silts and clays) at the beginning of runoff and about 67 percent by the end of runoff. For the Clearwater River, 98 percent of the suspended load was finer than sand at the beginning of runoff and 37 percent by the end of runoff. The bedload transport was also highly variable in terms of size fractions, sometimes exhibiting the majority of transport in the finer sand range and at other times the majority is in the coarse gravel and small cobble range. During some periods, a bimodal distribution was observed with significant transport in both these ranges.

Sediment transport information similar to that presented in the Jones and Seitz report (1980) is not available at many other points in the system. This type of information would greatly help in identifying areas of high sediment production. Only limited numbers of discrete suspended sediment measurements are available at Anatone (see: USGS 13334300 or Anatone at http://waterdata.usgs.gov/nwis/qwdata?).

Review of current and historic USGS suspended sediment measurement station data (Hydrosphere 2005) revealed only two other stations with reported daily suspended sediment discharge measurements. (Note: The Jones and Seitz 1980 study data does not show up in the daily discharge database). The two stations within the study area are located on the Tucannon River near Starbuck, Washington (record from 1961 to 1970) and the Palouse River at Hooper, Washington (record from 1961 to 1970).

An additional nine stations with daily suspended sediment data (Hydrosphere 2005) were found within the Snake River Basin, but are outside of the study area. Six are located on the North Fork of the Teton River (record from 1977 to 1978 which was the period after failure of Teton Dam in 1976); one on Bully Creek near Vale, Oregon (record from 1958 to 1962); and one on the Powder River near Baker City, Oregon (1960 to 1961). These eight stations are all within the portion of the Snake River basin above Hells Canyon and within the non-contributing area for sediment. The ninth station is on the North Fork of the Clearwater at Ahsahka, Idaho (1966 to 1968). This station is just below Dworshak Dam and was used to monitor the North Fork prior to construction of the dam.

The average annual sediment yield from the 431 square miles of the Tucannon near Starbuck, Washington over the period of 1961 to 1970 was 0.66 million tons per year. For the period from 1962 to 1970, the average annual sediment yield from the 2,500 square mile drainage for Palouse near Hooper, Washington was 1.0 million tons per year. These values are extremely high and represent sediment yields on the same order as the entire watersheds upstream of Lower Granite Reservoir. Further investigation of the hydrology during this period needs to be conducted since the reported annual sediment yields vary by two orders of magnitude over the period of record. This high yield may be partially the result of extreme runoff years. However, the data do indicate the high sediment production potential of the Palouse farmlands.

4.2.2 USDA Soil Conservation Service Basin -Wide Studies

The USDA Soil Conservation Service (SCS), now the NRCS, has conducted studies that estimate sediment delivery throughout the basin. The study that provided an estimate for the largest portion of the basin was associated with an effort to estimate the reduction in erosion and sediment delivery from implementation of the Food Security Act of 1985[1] (FSA) above Lower Granite (Reckendorf et al. 1988; Reckendorf et al. 1989). The sediment load to Lower Granite was estimated at the time of the study as 2.9 million tons/year (Note: the report provides conflicting estimates depending on which table is used – Table 1 or Table 2. The numbers quoted in this section were taken from Table 2). The estimate was comprised of 0.9 million tons/year from the Salmon, 1.2 million tons/year from the Clearwater and 0.8 million tons/year from the Snake below the Salmon, primarily the Grande Ronde. This estimate differs from the USGS in the much higher percentage of sediment from the Clearwater in the SCS study, 20 percent in the USGS versus 41 percent in the SCS. Additionally, the total is 2.9 million tons/year as opposed to 2.3 million tons/year by the

[1] The Food Security Act of 1985, as amended in 1990 and 1996, includes several provisions for the conservation of wetlands on agricultural lands and promotes wildlife habitat and water quality. It also has provisions for highly erodible lands (i.e., commodities produced on these types of lands are ineligible for certain Federal subsidies available to farmers). In addition, the Act provides for the establishment of conservation reserves, conservation set-asides, and conservation easement programs on existing farmlands (see Table 5).

USGS. The SCS study predicted nearly a 40 percent reduction in the delivery of sediment to Lower Granite under various alternative implementation scenarios for the programs in the FSA. The study addressed sediment reduction from dryland farm areas, since these were the same areas that the FSA would address.

Reduction estimates were determined for the non-irrigated farmland. The area with the highest potential for reduction was the area tributary to the Clearwater below the North Fork confluence (Middle Fork, South Fork, and Clearwater watersheds), with a reduction of 0.9 million tons per year from a 1.2 million tons per year level. The vast majority of this estimated reduction was in the Clearwater watershed. The next highest reduction was on Asotin Creek with sediment delivery dropping from 0.20 million tons per year to 0.04 million tons per year. A significant reduction in sediment delivery was also predicted for the Grande Ronde (Upper and Lower Grande Ronde and the Wallowa watersheds) with a decline in annual sediment delivery from 0.17 million tons per year to 0.04 million tons per year.

4.2.3 Preliminary Summary Observations

Based on the limited review of the sediment transport data and sediment yield estimates that cover the entire or most of the basin, several important observations have been made. First, there is limited “hard” sediment transport data to determine sediment yields from small or medium-scale areas within the basin. The Jones and Seitz (1980) study covers the majority of the sediment contributing area above Lower Granite. There are also some data available to directly characterize the sediment yield from the Palouse and Tucannon Rivers. These data show that these two relatively small portions of the watershed (about 10 percent) may contribute on the same order of sediment as the combined portions of the Clearwater and Snake above the USGS gages in the 1980 study.

The SCS studies (Reckendorf et al. 1989, Reckendorf et al. 1989) of the sediment yield to the Snake River tend to substantiate this characteristic of the watershed since it showed very high sediment yields from the dryland farm areas on the Palouse. Based on this preliminary assessment, the main area to target for sediment reduction may be the agricultural areas. The SCS study indicated that participation in the 1985 FSA by farmers in this region could reduce sediment yield to the Lower Snake River reservoirs by nearly 40 percent. However, it should be noted that 20 years have passed since the 1985 Food Security Act, so it is possible that many of the reductions its implementation may have already been realized. It could be of very high value in evaluating strategies for reduction of sediment yield to collect current data to determine if there has been a substantial reduction in sediment yield, as well as evaluate to the level that the various programs in the 1985 FSA have been implemented.

In general, recent data on major sediment sources and yields in the Snake River basin are limited. Coupled with this limited amount of information is the rapid expansion of habitat restoration (e.g., riparian plantings, stream stabilization), BMPs for agriculture and forestry, more stringent water quality requirements, and other activities that would tend to reduce sediment input to streams.

A number of data gaps would need to be filled in order to fully determine sediment sources and yields in the study area. These data would need to be recent and extended over a number of years to identify changes in sediment input that occur due to management activities (e.g., habitat restoration, changes in forestry and agriculture practices, or implementation of BMPs) and large-scale natural events (e.g., major floods or landslides). Coupled with this need for additional data is the need to identify very specific locations (either point or non-point sources), the amount and types (e.g., size, shape, type of material) of sediment being input, and transport times. All of these data gaps imply more detailed analysis is needed (e.g., field, laboratory, and office evaluations) to more firmly identify alternatives for reducing sediment transport to the Lower Granite and the other lower Snake reservoirs. Some of this information about specific sites might be developed through an intensive review of watershed and subbasin plans that address specific characteristics of stream reaches.

5. SALMON RIVER SUBBASIN

5.1 THE SETTING

5.1.1 Geography and Topography

The Salmon River subbasin covers approximately 13,984 square miles or almost 17 percent of the land of Idaho (Figure 3). It consists of 10 major watersheds with approximately 1,900 named streams. Table 7 shows the size of each of the watersheds (unique cataloguing units or 4th-field HUCs). Most of the subbasin is a mosaic of mountains and deeply cut valleys. Elevation within the subbasin ranges from 12,661 feet at the summit of Mount Borah down to 684 feet at the mouth of the Salmon River. The southeastern portion of the subbasin includes the high alpine of the Lost River and Lemhi ranges and the western portion encompasses the northern Seven Devils Mountains and the southern fringe of the Palouse Prairie region (NPCC 2004).

Key geologic features within the subbasin are the Idaho Batholith, Challis volcanics, and the Quaternary alluvial deposits of the Pahsimeroi and Lemhi valleys. Soils derived from these parent materials are typically highly erodible. Stream erosion has played the predominant role in shaping the physical features, creating relatively narrow, V-shaped valleys and steep valley side slopes. Large-scale, glacially derived features have contributed areas with broad U-shaped valleys and more localized glacial evidence (pothole lakes and cirques in the upper areas) at higher elevation features. The eastern Upper Salmon, Pahsimeroi, and Lemhi watersheds are an exception to this description. In the sub-parallel block fault ridges of the Lost River and Lemhi ranges give rise to high mountain peaks above broad, gentle valleys. The combination of the erodible soils, steep topography, and climatic stresses gives rise to significant base surface erosion, slumping, and debris avalanche hazards (NPCC 2004).

5.1.2 Hydrology

The western portion of the Salmon subbasin is Pacific maritime-influenced with most precipitation occurring as snow during the mild or cool winters and early springs. The easternmost portion of the subbasin (primarily the Lemhi, Pahsimeroi, and Upper Salmon) has typically one-half the precipitation of that received in the west of the subbasin due to the rain shadow effect of the mountains. The winters in the east are relatively dry and precipitation frequently occurs in the early summer. During winter, extended durations of cold can cause water bodies to freeze with the potential of flooding or severe bank damage as the ice breaks from the banks. Diverse snowmelt patterns may cause significant runoff events. Additionally, rain on snow events can occur in the spring and contribute to increased stream flow (NPCC 2004).

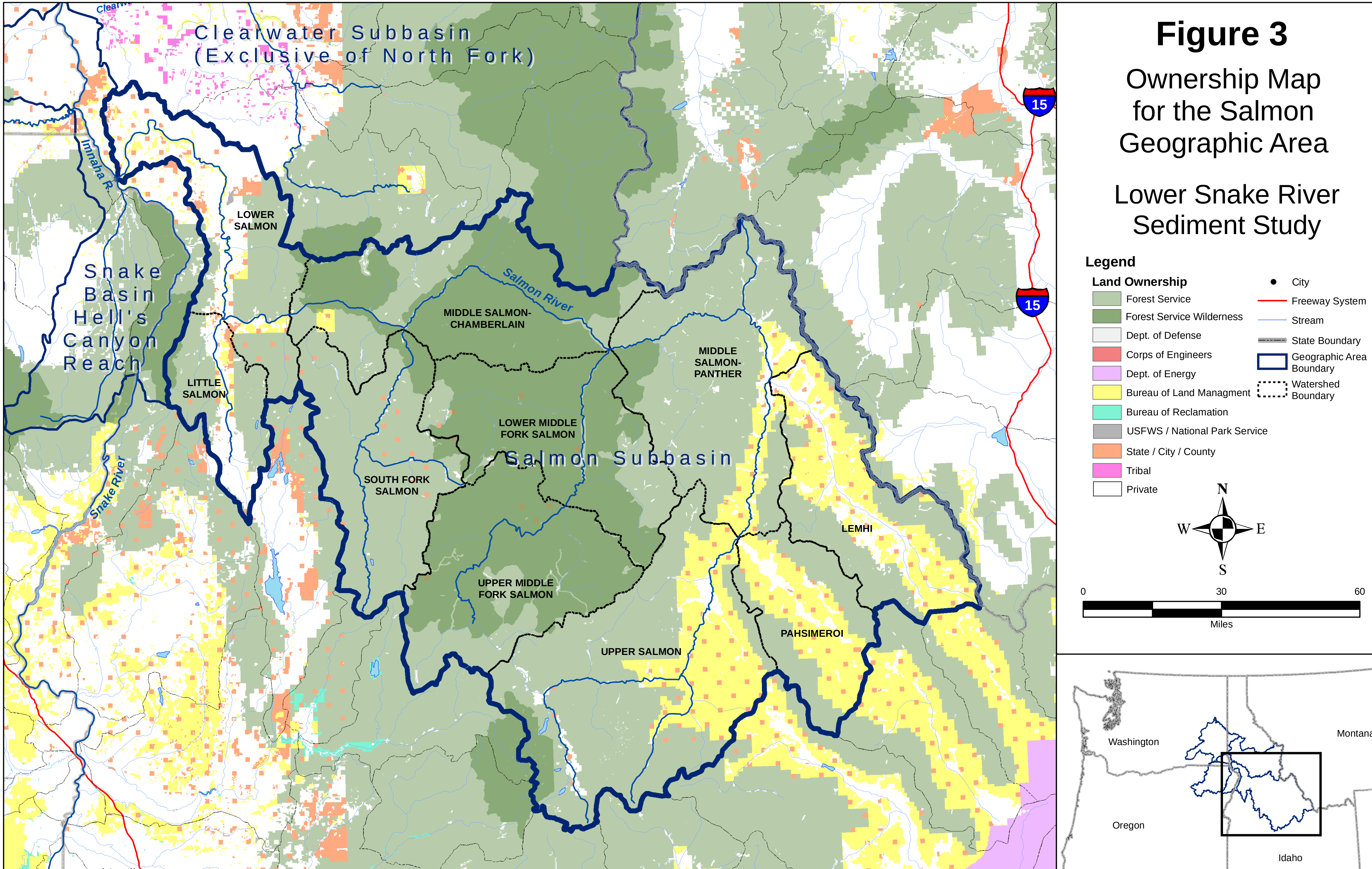

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Table 7. Size and Cataloging Unit Number for Watersheds within the Salmon Subbasin

Watershed Name	Cataloging Unit Number	Area (Square Miles)	Percent of Study Area
Upper Salmon	17060201	2,429	17%
Pahsimeroi	17060202	841	6%
Middle Salmon-Panther	17060203	1,809	13%
Lemhi	17060204	1,249	9%
Upper Middle Fork Salmon	17060205	1,501	11%
Lower Middle Fork Salmon	17060206	1,378	10%
Middle Salmon-Chamberlain	17060207	1,689	12%
South Fork Salmon	17060208	1,311	9%
Lower Salmon	17060209	1,208	9%
Little Salmon	17060210	579	4%
Total Subbasin		**13,994**	**100%**

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

The Salmon River flows 410 miles north and west through central Idaho, from its headwaters in Beaverhead, Salmon River, Lemhi, Lost River, Sawtooth, and smaller mountain ranges to its confluence with the Snake River in lower Hells Canyon. The Salmon River derives its flow from several primary tributaries including the Lemhi, Pahsimeroi, Middle Fork Salmon, South Fork Salmon, and Little Salmon Rivers. Records indicate that peak flows generally occur in May and June from snowmelt.

There are places in the basin with unique hydrologic factors that affects sediments in the streams. The Pahsimeroi and Lemhi watersheds contain few tributaries that contribute significant surface water to the mainstems and then primarily during high water years. Irrigation diversions combined with large natural percolation losses as the streams flow through alluvial deposits prevent the tributaries from contributing significant water flow. Most tributaries move underground while crossing alluvial deposits and appear as many springs as they move to the mainstems. The mainstem Pahsimeroi also flows beneath the surface for a five-mile section in the lower watershed. The result is that activity on the Federal lands in the upper watershed areas has little effect on the lower river water quality.

The waters percolate through the gravels during subsurface flow and thus, sedimentation problems are minimized [Idaho Soil Conservation Commission (ISCC) 1995].

In the mainstem Salmon in the Middle Salmon-Panther watershed, flooding of the Salmon River occurs frequently in the Deadwater area (approximately 4,000 feet long) between the North Fork Salmon River and Dump Creek. At the end of the Deadwater area, Dump Creek has created a large alluvial fan that pinches the Salmon River against the opposite bank. The fan at Dump Creek has been exacerbated in the last 100 years due to mining and logging, but existed before the area was settled. The Deadwater area resembles a long, narrow lake with slow currents and a flat bottom that freezes over completely in most winters and may include ice jams.

5.1.3 Land Cover

Forest (dry ponderosa pine/Douglas fir and mesic mixed conifer) occupies the greatest amount of area in the subbasin (70 percent or higher of cover in all but the Lemhi, Pahsimeroi, Upper Salmon and Lower Salmon watersheds). In the eastern watersheds – the Lemhi, Pahsimeroi, and Upper Salmon – shrub and grassland habitats are important, ranging from about 39 to 49 percent of cover. The Lower Salmon watershed has the greatest percentage of agricultural and urban types. Riparian and herbaceous wetlands are scarce, but distributed in all the watersheds and concentrated along the streams. The greatest density of wetlands is in the Lower Salmon and western portion of the Middle Salmon-Chamberlain watersheds. Table 8 shows general vegetation by watershed in the Salmon subbasin.

5.1.4 Land Ownership

National Forest System lands account for approximately 77 percent and BLM accounts for 13 percent of the total Salmon subbasin, leaving only 9 percent of the land as private (Table 9). The National Forest is concentrated in the middle portion and the BLM is primarily concentrated in the upper (eastern) portion of the watershed. Four of the central watersheds (South Fork Salmon, Middle Salmon-Chamberlain, Lower and Upper Middle Forks) are 99 percent National Forest. Three of those watersheds are almost entirely protected wilderness and the fourth, South Fork Salmon, has large roadless and unroaded areas. Two stream segments are federally designated as Wild, Scenic or Recreational Rivers: 125 miles of the Salmon River (from the mouth of the North fork Salmon to Long Tom Bar) and the entire Middle Fork Salmon (104 miles). Additionally, the larger water bodies within the South Fork Salmon subwatershed (e.g., South Fork Salmon, East Fork of the South Fork Salmon, Johnson Creek, and the Secesh River) are designated as Special Resource Waters by Idaho State. Special Resource Waters are specific segments or bodies of water recognized as "needing intensive protection to preserve outstanding or unique characteristics or to maintain current beneficial uses" [Idaho State Regulations: Idaho Administrative Procedures Act (IDAPA) 58.01.02.002.96].

Table 8. General Land Cover Percent by Watershed (Cataloging Unit) within the Salmon Subbasin (percent of total watershed area)

Watershed Name	Agricultural and Urban	Herbland	Shrubland	Early-seral Forest	Mid-seral Forest/ Woodland	Late-seral Forest	Other[1\]
Upper Salmon	<1%	13%	26%	30%	15%	15%	<1%
Pahsimeroi	2%	14%	35%	12%	23%	11%	2%
Middle Salmon-Panther	1%	11%	11%	11%	60%	5%	-
Lemhi	6%	31%	13%	7%	35%	7%	1%
Upper Middle Fork Salmon	-	4%	3%	50%	22%	22%	-
Lower Middle Fork Salmon	-	4%	7%	27%	41%	20%	<1%
Middle Salmon-Chamberlain	-	3%	<1%	19%	51%	27%	<1%
South Fork Salmon	-	1%	<1%	27%	35%	37%	<1%
Lower Salmon	19%	12%	<1%	16%	34%	19%	<1%
Little Salmon	6%	1%	<1%	36%	16%	40%	<1%
Total Subbasin	**3%**	**10%**	**10%**	**24%**	**34%**	**19%**	**<1%**

1\ Riparian, Alpine, Water, Rock, Barren

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

Table 9. Land Ownership by Watershed (Cataloging Unit) within the Salmon Subbasin (percent of total watershed area)

Watershed Name	Private	State / County/ City	Forest Service (non-Wilderness)	Forest Service Wilderness	BLM (non-Wilderness)
Upper Salmon	4%	2%	65%	4%	25%
Pahsimeroi	9%	2%	45%	-	44%
Middle Salmon-Panther	4%	<1%	80%	5%	11%
Lemhi	18%	3%	40%	-	40%
Upper Middle Fork Salmon	<1%	-	23%	77%[2\]	-
Lower Middle Fork Salmon	<1%	<1%	19%	80%[3\]	-
Middle Salmon-Chamberlain	<1%	<1%	30%	69%	1%
South Fork Salmon	<1%	<1%	90%	8%[4\]	0%
Lower Salmon	48%	5%	41%[1\]	1%	6%
Little Salmon	31%	3%	58%	4%	3%
Total Subbasin	**9%**	**1%**	**50%**	**27%**	**13%**

1\ Includes 1,977 National Park Service acres (<1% watershed).
2\ Includes 1977 acres managed by BLM and 366 privately owned acres in Frank Church River of No Return Wilderness.
3\ Includes 1,328 acres managed by BLM and 322 privately owned acres in Frank Church River of No Return Wilderness.
4\ Includes 625 acres managed by Idaho State.
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

Private land is concentrated in the valley bottoms of the upper and lower portions of the Salmon subbasin. Only three subwatersheds are greater than 10 percent private land with the Lower Salmon, Little Salmon and Lemhi watersheds at 50, 32 and 18 percent private land. Private landowners also control management of the majority of land in the river bottom of the Pahsimeroi and Upper Salmon (NPCC 2004, ISCC 1995). Table 9 summarizes land ownership by watershed within the Salmon subbasin.

5.1.5 Land Use

Historically, cattle ranching, logging, and mining have played important economic roles in the subbasin economy. Ninety percent of the Salmon subbasin is in Federal management and 27 percent of the subbasin is in designated wilderness. Approximately one-third of the National Forest is actively managed for timber or rangeland and much of BLM land is managed for rangeland for a total of approximately 40 percent of the Federal land.

Ranching and agriculture for cattle feed are important activities, especially in the eastern and western subbasin. Grazing on Federal lands is an important part of the livestock operations. It provides allotments for use through the summer months where the regulations and location of the pastures reduce degradation of the streams compared to that on private land (NPCC 2004).

Native American tribes traditionally fished and hunted within the Salmon subbasin. The Nez Perce Tribe has the right to fish in traditional and accustomed sites in the Salmon subbasin through the Treaty of 1855. The Shoshone-Bannock Tribes have the right to fish on unoccupied Federal lands through the 1868 Fort Bridger Treaty. The extent of the Shoshone-Paiute Tribes' fishing right is unresolved pending research and evaluation (NPCC 2004).

The Salmon River subbasin includes portions of eight counties and is sparsely populated, with the largest communities within the subbasin being Salmon (population approximately 3,122) and Challis (population 909). On average, road densities appear low in this subbasin with 58 percent of the area being unroaded. However, they are quite variable. The subbasins range from over 75 percent unroaded (Upper Salmon, Lower Middle Fork Salmon and Middle Salmon-Chamberlain) to 75 percent moderate to high density of roads (Lower Salmon). Road density by watershed is listed in Table 10.

Table 10. Road Density by Watershed (Cataloging Unit) within the Salmon Subbasin (percent of total watershed area with specified road density)

Watershed Name	Road Miles per Square Mile					
	0 – 0.02	0.02-0.1	0.1-0.7	0.7-1.7	1.7-4.7	>4.7
Upper Salmon	67%	8%	8%	9%	7%	<1%
Pahsimeroi	52%	4%	17%	11%	16%	<1%
Middle Salmon-Panther	39%	12%	4%	33%	10%	2%
Lemhi	41%	9%	13%	19%	18%	<1%
Upper Middle Fork Salmon	90%	2%	4%	2%	2%	<1%
Lower Middle Fork Salmon	93%	3%	1%	2%	<1%	<1%
Middle Salmon-Chamberlain	76%	3%	2%	9%	10%	<1%
South Fork Salmon	55%	14%	7%	14%	8%	1%
Lower Salmon	9%	5%	9%	41%	28%	7%
Little Salmon	20%	10%	4%	31%	29%	7%
TOTAL SUBBASIN	58%	7%	6%	16%	11%	2%

Source: Map 3.28, Volume II, in Quigley and Arbelbide (1997). Data used to form these classes was statistically extrapolated from sampled 6th-field HUC road data.

5.2 OVERVIEW OF SEDIMENT TRENDS AND HISTORIC CHANGES RELATIVE TO SEDIMENT

In the central watershed, the protected status of the land (wilderness, roadless, protected streams) has resulted in little change in that part of the watershed. Since the mid 1800s, there has been grazing, logging, and mining on Federal, tribal, and private lands in the rest of the watershed. While timber activities and wood products continue to be important in some areas, it has declined for several reasons including sustainability issues, market issues, and environmental standards. Mining activities have also declined during the last century and the late 1990s has seen a further decline in Custer and Lemhi counties, the most important to mining. There has been an overall increase in farming, although the number of irrigated acres has changed little in the last 30 years. Grazing activity has not changed substantially over the last 40 years. Recreation and tourism, primarily in the summer, are also important to the region and with the increases in the population of surrounding areas, this is growing (NPCC 2004).

Timber harvest in the 1950's and 1960's was most active in the South Fork Salmon River. Between 1958 and 1965, a series of intense storms and rain-on-snow events created numerous landslides and slumps triggered by logging and road construction, inundating the river and some of its tributaries with heavy sediment load. The rain-on-snow events in the winter and spring of 1965 caused over 100 landslides, the majority of which were related to roads. Concerns over sedimentation and fish habitat resulted in the stopping of land-disturbing activities in the upper South Fork Salmon River drainage in 1965. In 1974, floods in the East Fork of the South Fork Salmon River drainage carried heavy loads of sediment and in 1996-97, a high magnitude flood and sediment delivery event occurred that was estimated to have a 20-year return period. While timber activity is not currently widespread in the South Fork Salmon River watershed, it is the roads built during past harvest activities that are an important source of sediment (IDEQ 2002). Since the 1965 events, the Forest Service initiated a watershed restoration program.

Table 11 presents some ratings, developed by the Interior Columbia Basin Ecosystem Management Project (Quigley and Arbelbide 1997), which can be used as overall indices of the relative level of disturbance in each watershed within the geographic area. The measures relate to the degree of hydrologic disturbance in forest and rangeland environments (based on the level of surface mining, dams, cropland conversion, and roads) and the degree of riparian disturbance in rangeland environments (based on the sensitivity of streambanks to grazing and the sensitivity of stream channel function to the maintenance of riparian vegetation).

Based on these ratings, some broad generalizations can be made. The overall level of disturbance is low in the subbasin. While the riparian disturbance rating in the Lemhi, Little Salmon and Lower Salmon is low, the Middle Fork, South Fork, and Clearwater watersheds are generally rated to have a moderate to high level of disturbance, depending on the category.

Table 11. Hydrologic Disturbance Rating of Forest and Rangeland Environments and Riparian Disturbance Rating of Rangeland Environments Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Salmon River Subbasin

Watershed Name	Hydrologic Disturbance Rating of Forest Environments	Hydrologic Disturbance Rating of Rangeland Environments	Riparian Disturbance Rating of Rangeland Environments
Upper Salmon	Low	Low	Low
Pahsimeroi	Low	Low	Low
Middle Salmon-Panther	Low	Low	Low
Lemhi	Mod	High	Low
Upper Middle Fork Salmon	Low	unclassified	unclassified
Lower Middle Fork Salmon	Low	Low	Low
Middle Salmon-Chamberlain	Low	Low	Low
South Fork Salmon	Low	Low	Low
Lower Salmon	High	Low	Mod
Little Salmon	Mod	Low	Mod

Source: Maps 2.34, 2.35, and 2.36, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

5.3 SEDIMENT SOURCES AND YIELD

5.3.1 Overview Studies on Erosion, Mass Wasting, and Sedimentation

In this section, ratings and other results from a number of overview studies that were conducted across the entire Columbia River basin or over larger areas are presented for perspective and comparison purposes. The methods behind these studies are summarized briefly below and in more detail in Section 4.1.

The Interior Columbia Basin Ecosystem Management Project, conducted by the Forest Service and the BLM (Quigley and Arbelbide 1997) developed various soil erosion, mass failure, and sediment hazard ratings for nonpoint sources for each watershed, relative to all Columbia Basin watersheds. The key ratings are shown for the Salmon subbasin, in Tables 12 and 13.

Table 12. Soil Erosion, Mass Failure, and Sedimentation Measures Relative to the Entire Columbia Basin by Watershed (Cataloging Unit) within the Salmon Subbasin

Watershed Name	Surface Soil Erosion Hazard	Earth Flow Hazard	Debris Avalanche Hazard	Sediment Delivery Potential	Sediment Delivery Hazard
Upper Salmon	Low - Mod	Mod - High	High	High	Low - Mod
Pahsimeroi	High	Low - Mod	Low – Mod	Low - Mod	Low - Mod
Middle Salmon-Panther	Mod - High	Mod - High	High	Mod - High	Mod - High
Lemhi	High	Low - Mod	Low – Mod	High	Mod - High
Upper Middle Fork Salmon	Low	Mod - High	High	High	Low - Mod
Lower Middle Fork Salmon	Mod - High	Mod - High	High	High	Mod - High
Middle Salmon-Chamberlain	Mod - High	Mod - High	High	High	Mod - High
South Fork Salmon	Low	Mod - High	High	High	Low - Mod
Lower Salmon	High	Mod - High	High	High	High
Little Salmon	Mod - High	Mod - High	High	High	High

Source: Maps 2.10, 2.11, 2.12, 2.13, and 2.15, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

Table 13. Road Erosion Hazard and Road Sediment Delivery Hazard Relative to the Entire Columbia Basin by Watershed (Cataloging Unit) within the Salmon Subbasin

Watershed Name	Road Erosion Hazard	Road Sediment Delivery Hazard
Upper Salmon	Mod - High	High
Pahsimeroi	Mod - High	Low - Mod
Middle Salmon-Panther	Low	Mod - High
Lemhi	Mod - High	Mod - High
Upper Middle Fork Salmon	High	High
Lower Middle Fork Salmon	Mod - High	High
Middle Salmon-Chamberlain	Mod - High	High
South Fork Salmon	High	High
Lower Salmon	Low - Mod	High
Little Salmon	Low - Mod	High

Source: Maps 2.16 and 2.17, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

NMFS (Baker et al. 2005) has developed a draft model for estimating increases in erosion rates relative to historical rates. Based on this study, erosion rates in most of the Salmon subbasin are predicted to be very close to historical rates (1 to 1.5 times). There are four exceptions. Erosion rates range up to 3 times the historical rate in the forested areas of the South Fork Salmon and the Middle Salmon – Panther watersheds. It ranges up to 3 times the historical rate in the forested areas of the Little Salmon and generally is 1.5 to 3 times historical values in the Lower Salmon with areas up to 6 times.

The USGS developed a landslide overview map (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas which are susceptible to landsliding in the conterminous United States. Within the Salmon subbasin, extensive areas are mapped with a moderate or high incidence of past landslides and a moderate or high susceptibility to future landslides. These areas occur in all watersheds, but especially the upper watersheds in the eastern half of the subbasin.

A NRCS analysis of cropland for 1997 in the conterminous United States found that the Salmon River subbasin had few areas with highly erodible cropland or areas of cropland with excess erosion (NRCS 2000). The only areas were on the northern edge of the Lower Salmon watershed (NRCS 2000).

5.3.2 Subbasin Studies

303(d) Water Quality

The 1998 list of Section 303(d) water quality impaired water bodies included 89 water bodies in the Salmon River subbasin. Of those segments, 88 were listed for sediment concerns. The list included 10 to 25 percent of the waters within the South Fork Salmon and Lower Salmon watersheds, 5 to 10 percent of the waters in the Little Salmon, Pahsimeroi, Middle Salmon–Panther, Lemhi, and Middle Salmon–Chamberlain watersheds, and less than 5 percent of the Upper Salmon, Upper Middle Fork Salmon, and Lower Middle Fork Salmon watersheds (NPCC 2004). It is the state’s responsibility to assess the streams and develop TMDLs for waters which do not comply with water quality standards or waters where beneficial uses are not supported due to a pollutant.

The general surface water criteria for sediment used by IDEQ in its assessments are from Idaho State Administrative Rules, Water Quality Standards and Wastewater Treatment Requirements (IDAPA 58.01.02.200.08). The State Rules read as follows: Sediment shall not exceed quantities specified in Section 250, or, in the absence of specific sediment criteria, quantities which impair designated beneficial uses. Section 250 of IDAPA specifies concentrations for individual pollutants that are based on categories of water and individual beneficial uses. For cold waters where aquatic life is the beneficial use, the guidelines specify turbidity less than 50 NTU (nephelometric turbidity units) (instantaneous) or 25 NTU

(10 day average) greater than background. Further, IDAPA 58.01.02.070 specifies that "where natural background conditions from natural surface or ground water sources exceed any applicable water quality criteria…that background level shall become the applicable site-specific water quality criteria". Much of the water quality monitoring data from various sources includes monitoring the total suspended solids (TSS) or bedload which are rarely collected concurrently. Therefore, IDEQ often uses surrogate measures for determining sediments including turbidity, TSS data, cobble embeddedness, and/or streambank stability.

Assessments of many of the 303(d) listed streams have been completed since 1998 and while TMDLs have been developed for some of the streams, several streams have been found to support beneficial uses and have been recommended for delisting. In the Upper Salmon River watershed, only Challis Creek was recommended for remaining on the Section 303(d) list and its TMDL identified a sediment target of reducing the component of subsurface fine sediment less than 6.35 mm to below 28 percent. A target of 80 percent stream bank stability to reduce erosion was thought to be effective in reaching that subsurface fine sediment goal (IDEQ 2003). The Pahsimeroi River watershed assessment recommended that only the mainstem Pahsimeroi River remain on the 303(d) list. Bank erosion along the river itself was thought to be contributing excess sediment as the lack of hydrologic connections likely prevented tributaries from contributing sediment to the river. The state water quality monitoring data in 2000 (see Beneficial Use Reconnaissance Program described in Section 5.4) showed stretches of the Pahsimeroi that included 35 to 45 percent fines and bank stability as low as 31 and 43 percent (IDEQ 2001). In the Lemhi watershed, 8 tributaries remained on the 303(d) list for sediments and TMDLs were developed. Streambank erosion and road erosion were considered to be the most important sources of sediment to the tributaries (IDEQ 1999). In these three upper watersheds (Pahsimeroi, Lemhi, and Upper Salmon), stream bank erosion due to cattle management and resulting lack of stream bank stability is considered a very significant source of sediment (ISCC 1995).

In the Little Salmon watershed assessment for water quality, no streams were recommended for remaining on the 303(d) list. Suspended sediments were sampled in the lower Little Salmon in 2004 by the Department of Agriculture for water quality assessment. There were no major peak concentrations and the overall suspended sediment concentrations averaged 2 to 4 milligrams per liter (mg/l) and never exceeded 9 mg/l. It was noted in the report that due to the nature of the sampling schedule (every 2 weeks) sediment runoff events may have been missed. Highway 95, built in 1938 and realigned in 1964, has resulted in channel, riparian, and floodplain encroachment, including channel constriction. Coarse sediment was transported during the 1997 flood and remains in the channel and side channel. Therefore, the Little Salmon River below Round Valley Creek was recommended by IDEQ for listing for habitat alteration, not sediment. The changes in channel length and width over time are being studied to help quantify the slope and sediment transport (IDEQ 2005).

In the Middle Salmon-Panther and Middle Salmon – Chamberlain subwatershed assessments for water quality, no streams were recommended for remaining on the 303(d) list for sediments. Dump Creek, a significant source of sediments over time, was recommended for removal from the 303(d) list because the conditions are being addressed by the Salmon-Challis National Forest with appropriate standards and practices and conditions are improving. The drainage has been assessed over a number of years and the general conclusion is that slumping of the canyon will continue until it reaches an equilibrium condition (IDEQ 2001). It was noted in the Middle Salmon – Chamberlain assessment that erodible soils, fire history, and periodic intense climatic events have resulted in substantial natural erosion and delivery of sediment to the Salmon River. Large increases in natural sediment generally are associated with early spring rains and later with higher flows from snowmelt runoff. In most years, suspended sediment ranged from 2 mg/l to 65 mg/l, except in May when it ranged from 6 mg/l to 503 mg/l. The Middle Salmon River generally has levels below 25 mg/l suspended sediment but can significantly increase during climactic events (Shumar 2002).

The South Fork subwatershed analysis by IDEQ recommended that only the mainstem of the South Fork Salmon remain on the list. Review of the biological and sediment data and sediment affecting aquatic habitat indicates that the habitat conditions within the watershed are improving and in the process of re-establishing historical conditions. While the data used in the subwatershed assessment suggests that the watershed has attained the cobble embeddedness targets set in the 1991 TMDL, it has not attained the target for percent depth fines. After the TMDL for sediments was developed in 1991, the Forest Service initiated projects to meet the objectives and many are underway (listed in IDEQ 2002). The recommendation in the more recent assessment was to focus additional efforts on road management activities (IDEQ 2002).

There has been considerable sediment monitoring data for the South Fork Salmon, beginning after the large sediment depositions in the mid 1960's. Nelson and Burns (2004) reported free matrix counts, embeddedness measurements, surface fines estimates, core sampling, and photography for 1983 to 2003. The IDEQ South Fork Salmon Subbasin Assessment Addendum reports percent depth fines (8 sites) and cobble embeddedness (4 sites) for 1993 to 2001. The routine monitoring of the South Fork Salmon by the Forest Service started after the large landslide depositions in 1965. The monitoring reports include interstitial, surface sediment and intergravel conditions at several sites (varies by year) from 1966 to 2003.

The Middle Fork (Upper and Lower) do not have a completed assessment to review the 1998 303(d) listing. Less than 5 percent of these two watersheds are on the 1998 303(d) list and the majority of the watersheds are federally protected wilderness. While these watersheds have been monitored by the Forest Service, USGS, and IDEQ, most is not available and there is very little summary data in reports that can be referenced.

Adjudication Studies

A sediment analysis project was done for 20 sites in the Salmon subbasin by the Boise Aquatic Sciences Lab of the Rocky Mountain Research Station, Forest Service, to support the Snake River Adjudication Proceedings. In the Salmon subbasin, there were nineteen studies done in seven watersheds. The analyses includes channel profile and cross-section, geometry, discharge, channel material, sediment transport, and in some cases bedload transport rate versus discharge for selected size classes, and transport distance of painted rocks. The data not summarized below are in site summaries available on line at:

http://www.fs.fed.us/rm/boise/teams/soils/Bat%20WWW/index.htm.

The undated summaries with separate data spreadsheets have been referenced in the project document index with Forest Service, Rocky Mountain Research Station, and the stream name.

Lemhi River Watershed

- Hawley Creek, tributary to Eighteenmile Creek in the upper part of the Lemhi River watershed, about 0.7 miles upstream from the National Forest boundary - Streamflow and sediment data were collected from 1990 to 1996 and other information was collected for the study (pebble counts and stream reach survey). Stream discharges ranged from 9.83 cubic feet per second (cfs) to 94.6 cfs, bedload transport ranged from 0.00704 to 2.89 tons per day, and suspended transport ranged from 0.016 to 47.3 tons per day. Over the range of measured discharges, suspended transport accounts for approximately two to three fold difference at the lowest discharge and over a six fold difference at the highest discharge more than the bedload transport (USDA Forest Service undated).

Upper Salmon

- Herd Creek, tributary of the East Fork of the Salmon River, about 1.6 miles upstream of the confluence with the East Fork Salmon River - The stream is on land managed by the Bureau of Land Management. Streamflow, sediment data, pebble counts, painted rock transport, and stream reach survey were collected in 1994 and 1995. Stream discharges ranged from 10.2 cfs to 287 cfs, bedload transport ranged from 0.000964 to 60.2 tons per day, and suspended transport ranged from 0.265 to 218 tons per day. Over the range of measured discharges, suspended transport accounted for four to over five fold greater transport rate than the bedload transport rate (USDA Forest Service undated).

- Fourth of July Creek, tributary of the Salmon River, 2.9 miles east of Highway 75 - The stream is on Forest Service land. Streamflow and sediment data were collected from 1994 to 1997 and other information was collected for the study (pebble counts, stream reach survey, painted rock transport). Stream discharges ranged from 5.46 cfs to 137 cfs, bedload transport ranged from 0.00034 to 10.4 tons per day, and suspended transport ranged from 0.0952 to 71.7 tons per day. Over the range of measured discharges, suspended transport accounts for the majority of the material in transport with approximately an order of magnitude greater suspended transport at the lowest discharges and about three times as much at the highest discharges (USDA Forest Service undated).

- Salmon River, Yankee Fork, near Clayton, ID) - The stream is on Forest Service land. Sediment, pebble counts, reach survey, and core samples were taken in 1999 and 2000; streamflow records were available from 1922 to 1991. Sediment transport measurements spanned a range of stream discharges from 1,360 cfs to 5,070 cfs, bedload transport ranged from 0.111 to 328 tons per day, and suspended transport ranged from 17.0 to 4,730 tons per day. Over the range of measured discharges, suspended transport accounted for the majority of the material in transport by approximately and order of magnitude (USDA Forest Service undated).

- Salmon River near Obsidian, ID - The stream is on Forest Service land. Streamflow, sediment data and other information was collected for the study (pebble counts and core samples) were collected in 1999. Sediment transport measurements spanned a range of stream discharges from 264 cfs to 739 cfs, bedload transport ranged from 0.764 to 128 tons per day, and suspended transport ranged from 9.33 to 210 tons per day. Suspended transport accounts for the majority of the material in transport by approximately an order of magnitude greater at the lower range of measured discharges and about a two to three fold difference at the higher range of measured discharges (USDA Forest Service undated).

- Squaw Creek, two miles upstream from its mouth at the Salmon River - The stream is on Forest Service land. Streamflow and sediment data were collected from 1990 to 1996 and other information was collected for study (pebble counts, stream reach survey, and substrate surface material). Sediment transport measurements spanned a range of stream discharges from 0.76 cfs to 53.6 cfs, bedload transport ranged from 0.00833 to 12.1 tons per day, and suspended transport ranged from 0.00177 to 20.4 tons per day. At discharges near and larger than bankfull, suspended and bedload transport account for about equal proportions of the total sediment load. At lower discharges, suspended transport accounts for the majority of the material in transport (USDA Forest Service undated).

- Valley Creek, just upstream of its mouth at the Salmon River - The stream is on Forest Service land. Streamflow and sediment data were collected in 1994, 1995, and 1997. Other information collected for study was pebble counts, stream reach survey, substrate surface material, and core samples. Sediment transport measurements spanned a range of stream discharges from 139 cfs to 1,420 cfs, bedload transport ranged from 0.0077 to 89.8 tons per day, and suspended transport ranged from 1.08 to 223 tons per day. At discharges less than about 500 cfs, suspended transport accounts for the majority of the material in transport and at higher discharge bedload accounts for the majority of material in transport (USDA Forest Service undated).

- Thompson Creek is a tributary of the Salmon River near Clayton, ID - Streamflow and sediment data were collected in 1994 and 1995. Other information collected for study was pebble counts, stream reach survey, painted rock transport, and core samples. Sediment transport measurements spanned a range of stream discharges from 8.15 cfs to 124 cfs bedload transport ranged from 0.000627 to 22.0 tons/day, and suspended transport ranged from 0.154 to 63.7 tons/day. Over the range of measured discharges, suspended transport accounted for the majority of the material in transport by approximately an order of magnitude at the lowest discharges and about three times as much at the highest (USDA Forest Service undated).

Other Data

While there are many separate sediment or related studies of individual streams in the subbasin, there are few monitoring data sources that are consistent across space and time. PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program was initiated to determine whether PACFISH/INFISH management practices are effective in maintaining or improving the riparian conditions and to evaluate the effect of land management activities. Sampling, started in 2001 followed by a second sampling rotation beginning in 2006, will provide data to describe changes in conditions. Sampling sites were selected because they were thought to be the most likely location to show integrated effects from upstream management actions. There are several sites in each subwatershed in the Salmon River subbasin where both physical and biological monitoring are done. The monitoring protocols and other information are available on line at:

http://www.fs.fed.us/biology/fishecology/emp/

and the data can be accessed on:

http://svinetfc2.fs.fed.us/pibo/

There is also on-line data for the Salmon River subbasins that is consistently collected in Idaho. There is the USGS monitoring data on http://id.water.usgs.gov/public/wq/index.html and the IDEQ data on:

http://mapserver.deq.state.id.us/Website/deqwaters/viewer.htm.

Both of these sites provide the data from individual site visits for streams monitored in Idaho.

5.4 MANAGEMENT PRACTICES AND RESTORATION PROJECTS

As noted earlier, approximately 90 percent of the Salmon subbasin is federally owned (Forest Service and BLM). The BLM land and about one-third of the National Forest System land is actively managed leaving about 45 percent of the subbasin without potential for sediment production related to timber harvest or road construction and little potential to reduce sediment because it is naturally occurring from nonpoint sources.

The land managed by the Forest Service or BLM is managed under Forest Plans and Resource Management Plans (see Section 3.3.1) including Forest strategies and priorities. The Forests and BLM have adopted the more restrictive guidance set forth in interagency agreements (commonly known as PACFISH and INFISH) that specify Interim RMOs to maintain or restore properly functioning watersheds, riparian areas, and associated fish habitats. The interagency agreements were intended to be interim guidance until the forests each revised their plans. The Boise, Sawtooth, and Payette National Forests revised their plans jointly but did not substantively decrease the stream protection. The Nez Perce National Forest is jointly revising its plans with the Clearwater National Forest and they are not expected to substantively change stream protection. The Salmon-Challis National Forest has not revised their plans and is still guided by PACFISH and INFISH.

The Idaho Forest Practices Act and its amendments constitute minimum standards for forest practices on forest lands in Idaho; the Act primarily affects forest practices on state and private lands, because Forest Service and BLM forest practices are more restrictive. It establishes Stream Protection Zones (SPZs) around streams and limits practices within those SPZs. Skidding logs in or through streams is prohibited but there is no prohibition against slash burning within SPZs. Harvest practices must retain at least 75 percent of existing stream shade and leave trees are designated by number, distance from stream, stream width, and tree diameter. Class I streams (including lakes and streams used for domestic water supply and/or are important for spawning, rearing or migration of fish) have a designated SPZ of the area encompassed by a slope distance of 75 feet on each side of ordinary high water marks. The Class II SPZ for streams that contribute flow to Class I streams is the area encompassed by a slope distance of 30 feet on each side of the ordinary high water mark. Streams that do not contribute flow to Class I streams have minimum SPZs of 5 feet.

BMPs have been published in the Idaho Agricultural Pollution Abatement Plan (Resource Planning Ltd. 2003) for agriculture (including grazing), but are largely voluntary at this time. Improvements are generally implemented with willing landowners through the efforts of several agencies (e.g., soil and water conservation districts, Idaho Department of Fish and Game, Idaho Department of Water Resources), Nez Perce Tribe, and non-for-profit groups. The Clearwater Subbasin Management Plan (Ecovista 2003) includes general prioritization for watershed improvements to guide habitat improvement efforts on publicly and privately owned lands.

The IDEQ routinely monitors surface water quality using its Beneficial Use Reconnaissance Program (BURP). BURP is a monitoring program that combines biological monitoring and habitat assessment to determine the quality of Idaho's waters. The field manuals for standardized data collection and annual work plans are published on the IDEQ web site at:

> http://www.deq.state.id.us/water/data_reports/surface_water/monitoring/publications.cfm#burp

The Salmon Subbasin Management Plan, (Ecovista 2004), contracted by the Nez Perce and Shoshone-Bannock Tribes, prioritizes watersheds for priority actions. It identifies four priorities that do not directly address sediment; however, some actions resulting would affect sediments. The priorities are: 4) Travel management and access in all watersheds; 3) Minimize grazing impacts in Lemhi, Little Salmon, Lower Salmon, Upper Salmon, Pahsimeroi, and Middle Salmon-Panther; 2) Restore natural disturbance regimes in the Lower Salmon, Lemhi, Upper Salmon, Middle Salmon-Panther, and Pahsimeroi watersheds; and 1) Target prevention and reduction of exotic invasive plant species in the Middle Salmon-Chamberlain, Lower Middle Fork and Upper Middle Fork watersheds. The plan does not give more specific actions plans.

A summary list of restoration/habitat improvement projects in the Salmon River watershed is listed in Appendix 4 of the Salmon Subbasin Management Plan (Ecovista 2004). Most of the projects are recent (since 1990) but it does include projects started earlier. There are 97 pages with over 525 projects listed that occur in all watersheds. The list shows that many agencies and organizations are involved as funding sponsors and as principal implementing agency (Federal, state, local agencies, not-for-profit, and volunteer organizations are represented). Additional lists of pollution control projects that were or are being implemented in the watersheds are in the IDEQ Assessment and TMDL reports.

Upper Salmon Basin Watershed Project, formerly the Model Watershed Group, was initiated by the NPPC in 1992 to improve Chinook salmon and steelhead habitat in the Lemhi, Pahsimeroi, and East Fork of the Salmon River. It was changed to the Upper Salmon Basin Watershed Project in 2001 to include the North Fork and Yankee Fork Salmon Rivers, as well as the mainstem of the Salmon River from the mouth of the Middle Fork upstream to its headwaters, for habitat restoration watersheds. The Model Watershed Plan (ISCC 1995) was developed as part of the NPPC's Columbia River Basin Fish and Wildlife Program and is used to help direct BPA funding of projects. The plan was locally organized and involved the major resource manager and government agencies. It specifies habitat goals that include reducing the sediment levels within spawning gravels. It includes a prioritized list of streams within watersheds to guide fish screening and habitat improvement efforts on privately owned lands throughout the Upper Salmon Basin. The plan specifies the following highest priority actions that would affect sediment:

- Enhance and protect the riparian corridor along 3 miles of Herd Creek.
- Stabilize 10,000 feet of streambank in Herd Creek where the stream has widened.
- Maintain and enhance the riparian corridor along 17 miles of critical fish habitat in the reach from the river's mouth to Hooper Lane.
- Enhance 10 miles of riparian corridor in the Patterson-Big Springs reach through selective planting of trees and shrubs.
- Improve 12 irrigation diversions to provide stable diversion points and reduce erosion (Pahsimeroi mouth to Hooper Lane).
- Maintain and enhance the riparian corridor along the upper 10 miles of the Hayden Creek-to-Leadore reach.
- Stabilize streambanks in the 10-mile section from the bridge near Leadore to the Eightmile Creek confluence.

In 2005, the Upper Salmon Basin Watershed Project Technical Team (USBWPTT), which is comprised of professional technical experts and fisheries biologists from regional state, Federal, tribal agencies, and other groups, developed a prioritization process for the Upper Salmon Basin Watershed Project Area because the current demand for conservation funding assistance to landowners was greater than the available resources. While it is intended to address fish conservation needs, high sediment levels and lack of streamside vegetation are listed as two of the key limiting factors in the watershed analysis and would be issues that would be funded. The document provides the scores used to prioritize each steam and is intended to be used by funding agencies to set priorities (USBWPTT 2005).

5.5 SUMMARY OF PRELIMINARY CONCLUSIONS

Based on this review of available information, a few preliminary conclusions can be made regarding opportunities for sediment reduction. It appears that the most promising watersheds for reduction efforts would include the Lower Salmon, South Fork Salmon, and the Little Salmon in the lower portion of the subbasin and the Lemhi and Pahsimeroi watersheds in the upper subbasin. In these watersheds, it appears that primarily forest management and grazing land uses should be the focus of additional efforts at sediment control. Restoration of degraded riparian areas, streambank erosion projects, and preventing road failures and road erosion appear to be the projects with the highest potential for success.

6. CLEARWATER RIVER SUBBASIN

6.1 THE SETTING

6.1.1 Geography and Topography

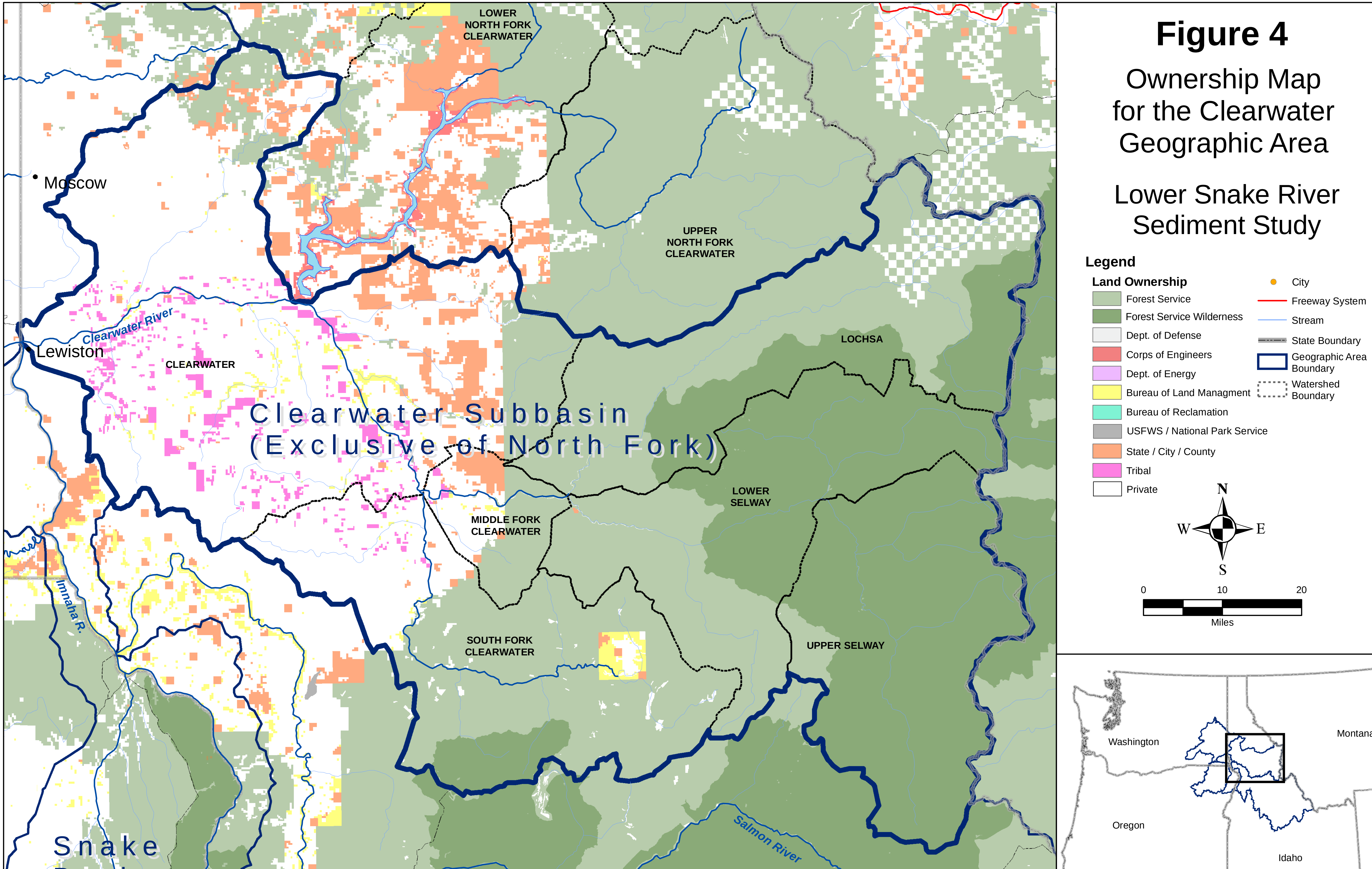
The Clearwater River subbasin is located primarily in north-central Idaho (less than 1 square mile occurs in Washington). It is bracketed by the Salmon River basin to the south and St. Joe River basin to the north. The Clearwater River drains approximately 9,353 square miles, with 6,907 in the study area. The Upper and Lower North Fork Clearwater watersheds are not in the study area because they lie above the Dworshak Dam, which effectively traps the vast majority of sediment from these watersheds. The Clearwater River originates in the Bitterroot Mountains at the Idaho/Montana border and flows to the Snake River at the Washington–Idaho border at the town of Lewiston, Idaho. Table 14 shows the size of each of the six watersheds (4th-field HUCs) in the project geographic area and their locations are shown in Figure 4.

Table 14. Size and Cataloging Unit Number for Watersheds within the Clearwater River Subbasin (does not include the Upper and Lower North Fork Watersheds)

Watershed Name	Cataloging Unit Number	Area (Square Miles)	Percent of Study Area
Upper Selway	17060301	986	14
Lower Selway	17060302	1,022	15
Lochsa	17060303	1,173	17
Middle Fork Clearwater	17060304	221	3
South Fork Clearwater	17060305	1,175	17
Clearwater	17060306	2,328	34
Total	**--**	**6,907**	**100%**

Note: The Upper North Fork Clearwater Watershed includes 1,295 sq. mi. and the Lower North Fork Clearwater Watershed includes 1,151 sq. mi.
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

From west to east, the basin is characterized by plateaus and foothills, divided by breaklands, and further east by the Selway-Bitterroot mountain range that forms the Idaho/Montana border. The breaklands lie mostly in the central portion of the basin, closely bordering the mainstem and most tributaries. The slope gradients in the breaklands average between 60 to 80 percent and contribute to sediment transport efficiency. The mountains in much of the basin include glaciated areas.



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Marine sediments followed by volcanic activity and uplift and extension with a major cycle of folding and faulting were important parts of the geologic history in this subbasin. Granite and schist are widespread throughout most watersheds and form the dominant parent materials, occurring on almost two-thirds of the subbasin. Granitics, common throughout the subbasin and more dominant in the east, have variable erodiblity influenced by weathering. Schists, widespread throughout north and south-central portions of the subbasin, are highly erodibile and are considered to represent among the least stable of all geologic materials in the subbasin. Basalt is an important parent material in the eastern third of the subbasin and the Palouse and Camas Prairie regions of the lower (western) portion of the subbasin, is covered by windblown loess. The ash loess cap was laid down to depths of 4–5 meters and has been largely eroded away on steeper and/or burned slopes. This deep, silt-sized material is easily transported through processes of erosion (Ecovista et al. 2003).

6.1.2 Hydrology

The Clearwater subbasin is influenced by warm, moist maritime air masses similar to other parts of the Lower Snake River basin. The southern and eastern high elevations experience drier and colder weather typical of the northern Rocky Mountains. Most precipitation occurs in the fall, winter, and spring, and is predominantly snow at the higher elevations. The subbasin can experience rain-on-snow events from November through March.

The mainstem Clearwater River contributes approximately one-third of the flow of the Snake River. The Clearwater derives its flow from four primary tributaries (North and South Forks of the Clearwater, Lochsa and Selway Rivers). The Selway and Lochsa Rivers both originate at the Idaho–Montana border along the Selway-Bitterroot divide and flow west to their junction at Lowell, Idaho. The confluence of the Lochsa and Selway form the Middle Fork of the Clearwater. The South Fork flows west and north to join the Middle Fork where it becomes known as the mainstem. From there it flows west to the Snake. Records indicate that peak flows generally occur in May and June from snowmelt (Ecovista et al. 2003).

Dworshak Dam, constructed in 1972, is located 2 miles above the mouth of the North Fork Clearwater River and regulates the flow to the Clearwater. It is the only major water regulating facility in the watershed. Because the dam stores water in a reservoir and effectively stores sediment, the North Fork is not included in the study area. There are 70 smaller dams in the Clearwater watershed, concentrated in the lower part of the watershed area. Surface water use is permitted in all subwatersheds, but is most common in the lower Clearwater, Lolo/Middle Fork, and South Fork areas. While there are 53 gauging stations in the Clearwater watershed, only 12 of the stations are currently active (Ecovista et al. 2003).

6.1.3 Land Cover

Coniferous forests make up approximately 70 percent of the vegetation and are concentrated in the mountainous eastern two-thirds of the subbasin. Cropland and pastureland makes up approximately 18 percent of the vegetation and is located largely in the western portion. Shrublands and herbaceous areas, primarily within forest lands, make up about 10 percent. Table 15 summarizes the extent of general land cover types within the subbasin, by 4th-field watershed.

Table 15. General Land Cover Percent by Watershed (4th-field HUC) within the Clearwater River Subbasin (percent of total watershed area)[1/]

Watershed Name	Agricultural and Urban	Herbland	Shrubland	Early-seral Forest	Mid-seral Forest/ Woodland	Late-seral Forest	Other[2/]
Upper Selway	-	-	<1%	33%	62%	4%	<1%
Lower Selway	-	-	-	32%	55%	12%	<1%
Lochsa	-	-	-	35%	57%	7%	1%
Middle Fork Clearwater	18%	6%	-	10%	58%	5%	2%
South Fork Clearwater	23%	<1%	-	10%	66%	1%	<1%
Clearwater	57%	2%	-	3%	38%	<1%	<1%
Total Basin[1\]	**24%**	**1%**	**<1%**	**19%**	**53%**	**4%**	**<1%**

[1/] Does not include the Upper and Lower North Fork Clearwater watersheds
[2/] Riparian, Alpine, Water, Rock, Barren
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

6.1.4 Land Ownership

The majority of the geographic area is federally owned with 62 percent of the land in the Clearwater and Nez Perce National Forests and an additional 1 percent under BLM management. Approximately 3 percent is owned by the State of Idaho, 1 percent by the Nez Perce Tribe, and the remaining 33 percent is privately owned. Most of the forested land is on National Forest System lands, but the state of Idaho, Potlatch Corporation, and Plum Creek Timber Company also own large forested areas. The western third of the watershed is mostly in private ownerships, especially timber companies, small timber landowners, farming and ranching families, and companies. Nez Perce Tribal lands are located primarily in the western half of the watershed within the current boundaries of the Nez Perce Reservation. The Nez Perce lands consist of both Fee lands owned and managed by the Nez Perce Tribe and properties placed in trust status with the Bureau of Indian Affairs. Tribal members also have land use rights in other areas.

Table 16 summarizes land ownership by watershed within the Clearwater subbasin and Figure 4 shows its spatial distribution. The Upper Selway, Lower Selway, and Lochsa watersheds are almost entirely under Forest Service management. The South Fork and the Middle Fork watersheds are 71 and 51 percent under Federal management (including BLM), respectively. In contrast, the Clearwater watershed is mostly in private ownership and only has 10 percent under Forest Service management.

Table 16. Land Ownership by Watershed (4th-field HUC) within the Clearwater River Subbasin (percent of total watershed area)[1/]

Watershed Name	Private	Tribal	State	National Forest (non-Wilderness)	National Forest Wilderness	BLM
Upper Selway	-	-	-	5%	95%	-
Lower Selway	<1%	-	-	42%	58%	-
Lochsa	5%	-	-	64%	31%	-
Middle Fork Clearwater	36%	<1%	11%	51%	0%	<1%
South Fork Clearwater	28%	<1%	<1%	60%	9%	2%
Clearwater	79%	4%	7%	10%	-	<1%[2/]
Total Basin[1\]	**33%**	**1%**	**3%**	**33%**	**29%**	**1%**

[1/] Does not include the Upper and Lower North Fork Clearwater watersheds.
[2/] Includes 66 acres of lands managed by the Corps.
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

6.1.5 Land Use

Approximately 29 percent of the Clearwater subbasin (not including the North Fork) is in designated wilderness and an additional 16 percent is designated in some other highly protected status, mostly inventoried roadless areas, but also including federally designated Wild and Scenic Rivers. The Selway-Bitterroot Wilderness encompasses portions of the Upper and Lower Selway and Lochsa watersheds. The Gospel Hump Wilderness extends into the southern edge of the South Fork watershed. The Upper Selway, Upper North Fork, Lochsa, and Lower Selway each have at least 75 percent of their land in protected areas (Ecovista et al. 2003). There are also 54 miles of Wild River and 131 miles of Recreational River (Federal Wild and Scenic River classifications) in the Clearwater watershed, which were federally designated in 1968. Protected areas include the Lochsa River from the Powell Ranger Station and the Selway River from its origin, both downstream to Lowell where they meet and form the Middle Fork Clearwater. The Middle Fork Clearwater is designated from its origin at Lowell downstream to Kooskia, Idaho.

Agriculture (primarily wheat and barley) and grazing dominate the western part of the watershed, with grazing extending into the National Forests. Historically, the Forest Service was the largest producer of timber, but in 1996, harvest began to be dominated by private companies and individuals. Plum Creek Timber Company operates within the Upper North Fork with some landholdings in the Lochsa watershed, the Potlatch Corporation operates primarily in the Lower North Fork and Lolo/Middle Fork areas, and the Nez Perce Tribe is active on tribally managed lands primarily within the Lower Clearwater and South Fork Clearwater areas. Mining has historically occurred throughout the entire watershed, but has been most dense in the South Fork drainage. Its current importance is greatly reduced.

Roads on the plateau in the southwestern part of the watershed include rural roads and farm access roads. The highest road densities are in the center of the subbasin due to logging roads, where they typically range from 3 to 5 miles/square mile. Due to their protected status, there are very few existing roads and a low potential for road development in the eastern part of the watershed (Table 17).

Table 17. Road Density Predicted Classes by Watershed (4th-field HUC) within the Clearwater River Subbasin (percent of total watershed area)

Watershed Name	Road Miles per Square Mile					
	0 – 0.02	0.02-0.1	0.1-0.7	0.7-1.7	1.7-4.7	>4.7
Upper Selway	95%	3%	<1%	<1%	<1%	-
Lower Selway	60%	4%	1%	13%	22%	<1%
Lochsa	46%	2%	2%	18%	29%	3%
Middle Fork Clearwater	3%	2%	7%	33%	48%	6%
South Fork Clearwater	10%	1%	8%	33%	43%	5%
Clearwater	1%	<1%	26%	44%	24%	5%
Total Basin	**32%**	**2%**	**11%**	**26%**	**25%**	**3%**

Source: Map 3.28, Volume II, in Quigley and Arbelbide (1997). Data used to form these classes was statistically extrapolated from sampled 6th-field HUC road data.

6.2 OVERVIEW OF SEDIMENT TRENDS AND HISTORIC CHANGE

Since the mid-1800s, there has been grazing, logging, and mining on Federal, tribal, and private lands in this subbasin. The first significant commercial logging began in the Clearwater in the 1880s, but it did not start on a large scale until 1927. Logging on the national forests was minimal prior to WWII: the largest annual cut on the Clearwater National Forest prior to 1946 was 18 million board feet (MMBF). After the war, the annual cut increased dramatically and was at or above 100 MMBF from 1959 until the 1990s when it began to decline. Much of the reduction in timber harvest on Federal land has been due to restrictions related to fish and wildlife and lack of resolution on the management of remaining roadless areas.

The South Fork Clearwater drainage has a complex mining history that included periods of intense placer, dredge, and hydraulic mining. Currently, mining claims are distributed throughout the Clearwater watersheds, with the lowest number of occurrences in the Selway watersheds (where the majority of the land is in wilderness). Ecological hazard ratings for mines (delineated by the Interior Columbia Basin Ecosystem Management Project) indicate that most of mines in the Clearwater River subbasin have a rating of relatively low environmental risk. However, there are mines with relatively high ecological hazard ratings in the South Fork and in the Orofino Creek drainages (Ecovista et al. 2003).

Table 18 presents some ratings, developed by the Interior Columbia Basin Ecosystem Management Project (Quigley and Arbelbide 1997), which can be used as overall indices of the relative level of disturbance in each watershed within the geographic area. The measures relate to the degree of hydrologic disturbance in forest and rangeland environments (based on the level of surface mining, dams, cropland conversion, and roads) and the degree of riparian disturbance in rangeland environments (based on the sensitivity of streambanks to grazing and the sensitivity of stream channel function to the maintenance of riparian vegetation).

Based on these ratings, some broad generalizations can be made. The overall level of disturbance is low in the Upper and Lower Selway and the Lochsa watersheds. In contrast, the Middle Fork, South Fork, and Clearwater watersheds are generally rated to have a moderate to high level of disturbance, depending on the category.

Table 18. Hydrologic Disturbance Rating of Forest and Rangeland Environments and Riparian Disturbance Rating of Rangeland Environments Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Clearwater River Subbasin

Watershed Name	Hydrologic Disturbance Rating of Forest Environments	Hydrologic Disturbance Rating of Rangeland Environments	Riparian Disturbance Rating of Rangeland Environments
Upper Selway	Low	Low	Low
Lower Selway	Low	Low	Low
Lochsa	Low	Unclassified	Unclassified
Middle Fork Clearwater	High	High	Low
South Fork Clearwater	Moderate	Moderate	High
Clearwater	High	High	Moderate

Source: Maps 2.34, 2.35, and 2.36, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

6.3 SEDIMENT SOURCES AND YIELD

6.3.1 Overview Studies on Erosion, Mass Wasting, and Sedimentation

In this section, ratings and other results from a number of overview studies that were conducted across the entire Columbia River basin or over larger areas are presented for perspective and comparison purposes. The methods behind these studies are summarized briefly below and in more detail in Section 4.1.

The Interior Columbia Basin Ecosystem Management Project conducted by the Forest Service and the BLM (Quigley and Arbelbide 1997) developed various soil erosion, mass failure, and sediment hazard ratings for nonpoint sources for each watershed, relative to all Columbia Basin watersheds. The key ratings are shown for the Clearwater subbasin in Tables 19 and 20.

Table 19. Soil Erosion, Mass Failure, and Sedimentation Measures Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Clearwater River Subbasin

Watershed Name	Surface Soil Erosion Hazard	Earth Flow Hazard	Debris Avalanche Hazard	Sediment Delivery Potential	Sediment Delivery Hazard
Upper Selway	Low - Mod	Mod - High	High	High	Mod - High
Lower Selway	Low - Mod	High	High	High	Mod - High
Lochsa	Low - Mod	High	High	High	Mod - High
Middle Fork Clearwater	High	High	High	High	High
South Fork Clearwater	Mod - High	Mod - High	High	Mod - High	High
Clearwater	High	High	High	Mod - High	High

Source: Maps 2.10, 2.11, 2.12, 2.13, and 2.15, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

Table 20. Road Erosion Hazard and Road Sediment Delivery Hazard Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Clearwater River Subbasin

Watershed Name	Road Erosion Hazard	Road Sediment Delivery Hazard
Upper Selway	High	High
Lower Selway	Mod - High	High
Lochsa	High	High
Middle Fork Clearwater	Low	Mod - High
South Fork Clearwater	Low	Mod - High
Clearwater	Mod - High	Mod - High

Source: Maps 2.16 and 2.17, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

NMFS (Baker et al. 2005) has developed two draft models for estimating increases in erosion rates relative to natural levels. Based on this study, erosion rates in the Upper and Lower Selway and Lochsa watersheds have not changed much and are 1 to 1.5 times historical rates. The Middle Fork Clearwater watershed was modeled to have increased erosion rates of 1.5 to 3 times the historical rate. The South Fork Clearwater and the Clearwater watersheds have erosion rates up to 10 times the historic rate or greater. In both cases the higher values are primarily in agricultural areas of the lower watersheds. In the South Fork Clearwater, the upper watershed, including the wilderness, has shown little change and is close to 1 times the historical rate.

The USGS developed a landslide overview map (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas which are susceptible to landsliding in the conterminous United States. Within the Clearwater subbasin, localized areas with a moderate incidence of past landslides and high susceptibility to future landslides were identified in the lower portion of the Lochsa watershed, the Lower Selway watershed, and in the upper Clearwater watershed.

A NRCS analysis of cropland for 1997 in the conterminous United States found that the Clearwater River watershed and the lowermost portion of the South Fork watershed have areas of highly erodible cropland and areas of non-highly erodible cropland (NRCS 2000). Both categories of croplands had areas with excess erosion above the tolerable soil erosion rate (NRCS 2000).

6.3.2 Subbasin Studies

In the Clearwater Subbasin Assessment (Ecovista et al. 2003), two types of sedimentation were modeled, mass wasting and surface erosion hazard. A model developed by University of Idaho and Potlatch Corporation was used for projecting mass wasting potential and combined with another model developed by the Washington State University (WSU) Center for Environmental Education to provide input regarding the likelihood that the sediment from mass wasting would enter the streams. The results showed that the subbasin has high erosion hazard due to its steep slopes and unstable parent materials (such as schist). This hazard, combined with storm events and older roads or bare ground, were found to favor mass wasting in the central and eastern portions of the subbasin. The mobilized sediment was considered to be most likely conveyed to stream channels in the Lower and Upper Selway, in the lower Lochsa, in the South Fork Clearwater River, and in the North Fork Clearwater above Dworshak Reservoir (Ecovista et al. 2003).

A second modeling exercise looked at surface erosion hazard data for the watershed. When vegetation cover is considered, potential sedimentation ratings were highest in the lower Clearwater, Lolo/Middle Fork and Lower North Fork areas, and lowest in the South Fork and Lochsa areas. Surface erosion within the Clearwater watershed is considered to be highest in the agricultural areas in the western portions of the watershed. The erosion in the agricultural areas is largely determined by agricultural practices and programs run by NRCS have recently improved some of the worst erosion on these lands (Ecovista et al. 2003).

Forest management activities have been shown to increase the number of landslides. An analysis of the 1995–1996 landslides, due to rain-on-snow events, estimated that approximately 71 percent of the sediment that reached the streams was from natural landslides and 29 percent was caused by roads and timber activities (IDEQ 2000).

In a study conducted by the University of Idaho, the RUSLE was applied to estimate erosion due to sheet and rill erosion in non-forested areas and the Water Erosion Prediction Project (WEPP) model was used to estimate erosion and delivery of sediment from road surfaces. In this analysis, roads were assumed graveled with a non-eroding ditch; therefore, road erosion and sediment delivery may be somewhat underestimated. The results of the analysis of agriculturally dominated areas in the Clearwater subbasin showed that erosion from roads accounted for less than 1 percent of the total estimated erosion, and sheet and rill erosion from agricultural fields accounted for the rest. Likewise, sediment delivery showed that roads accounted for 1 percent of the total estimated sediment delivery and sheet and rill erosion from agricultural fields accounted for 99 percent (Boll et al., 2002).

A study was conducted at WSU for the IDEQ to estimate ephemeral gully and stream channel erosion in the Potlatch River watershed. Aerial survey techniques and analysis of seasonal high resolution aerial images was used. Approximately 1,250 miles of ephemeral and stream channels were estimated to exist in the six primary agricultural subbasins of the lower Potlatch River watershed (Big Bear, Cedar, little Bear, Little Potlatch, Middle Potlatch, and Pine basins). Ephemeral gully erosion was estimated at less than 0.5 tons per acre in

2003-2004. A channel sediment study found that channel sediment is a small fraction of the reported annual land surface erosion in the basin. The two estimates of channel sediment provided a high geomorphic estimate of 0.21 tons per acre per year and a low channel survey-based estimate of 0.06 tons per acre per year. Erosion in ephemeral gullies in western part of the study area was noted to be caused mostly by rain after spring tillage (Teasdale and Barber 2005).

The 1998 list of Section 303(d) water quality limited stream segments included approximately 540 miles of stream within the Clearwater watershed (not including the North Fork). Approximately 70 percent of the miles are in the Lower Clearwater, 19 percent in the Middle Fork Clearwater, and 9 percent are in the South Fork Clearwater. The Upper and Lower Selway and Lochsa watersheds, with a high portion of wilderness or inventoried roadless area, had a limited number of stream miles listed as water quality limited in the 1998.

Several assessments of the listed streams have been completed since 1998 and while TMDLs have been developed for some of the streams, several have been found to support beneficial uses and have been recommended for delisting. The South Fork Clearwater TMDL Assessment (not including Cottonwood Creek) projected sediment loadings from agricultural and grazing areas of approximately 10-30 times natural background in the lower watershed while sediment from forested areas was projected to be no greater than twice natural background. Seven of the ten stream segments were recommended for delisting (IDEQ 2000 and 2003). Cottonwood Creek, which was analyzed separately, remained on the 303(d) list, and TMDLs were developed for sediments and other pollutants (IDEQ and Nez Perce Tribe 2000). Several segments in the portion of the Lower Clearwater, Jim Ford Creek area, have remained on the 303(d) list and TMDLs have been developed (IDEQ and Nez Perce Tribe 2000). In the Lochsa River and Selway watersheds, streams segments that were listed for sediment were recommended for delisting. The management practices implemented on publicly owned land are expected to improve water quality and the current level of sedimentation is not considered to have impaired beneficial use of the area (Bugosh 1999, 2000).

Most of the TMDL analyses have general information regarding the source of sediments to the streams. In the Selway, sediment loading to waters was more specifically estimated to be 25 percent from roads, 4 percent from timber harvest areas, and 71 percent from natural landslides (Bugosh 2000).

Adjudication Studies

While there are many separate sediment or related studies of individual streams in the basin, there are few monitoring data sources that are consistent across space and time. A sediment analysis project was done for Idaho streams by the Boise Aquatic Sciences Lab of the Forest

Service Rocky Mountain Research Station (USDA Forest Service 2005) to support the Snake River Adjudication Proceedings. In the Clearwater River Basin, there were seven studies done in four watersheds. While there is some variability in the data available or collected, all sites included sediment transport at various stream discharges. The analyses also include other measurements such as channel profile and cross section, geometry, channel material, bedload transport rate versus discharge for selected size classes, and transport distance of painted rocks. The data not summarized below is in site summaries available on line at:

http://www.fs.fed.us/rm/boise/teams/soils/Bat%20WWW/index.htm

The undated summaries with separate data spreadsheets have been referenced in the project document index with Forest Service, Rocky Mountain Research Station, and the stream name.

Lochsa Watershed

- Lochsa River, about one mile from its confluence with the Selway – The stream is on National Forest. Sediment transport measurements were made during water years 1994 through 1997. Additional information collected at this site includes a survey of the stream reach, pebble counts and core samples. The measurements spanned a range of stream discharges from 3,910 to 26,800 cfs; bedload transport ranged from 0.0800 to 346 tons/day; and suspended transport ranged from 14.7 to 37,100 tons/day. Suspended transport accounted for the majority of the material in transport over the range of measured discharges by between one and two orders of magnitude (USDA Forest Service undated).

Selway Watershed

- Selway River near Lowell, ID - The stream is on National Forest. Streamflow and sediment data were available from 1994 to 1997 and other information was collected for the study (pebble counts, stream reach survey, core samples). Stream discharges ranged from 4,760 cfs to 37,700 cfs; bedload transport ranged from 0.1 to 368 tons/day; and suspended transport ranged from 16.6 to 64,300 tons/day. Over the range of measured discharges, suspended transport accounted for the majority of the material in transport by an order of magnitude (USDA Forest Service undated).

South Fork Clearwater Watershed

- Johns Creek at its confluence with the South Fork Clearwater River – The stream originates in the Gospel Hump Wilderness and is managed by the Forest Service. Streamflow and sediment data were available from 1986 to 1995 and other information was collected for the study (pebble counts, stream reach survey and core samples). Stream discharge ranged from 21.1 cfs to 1,210 cfs; bedload transport ranged from 0.0007 to 23.5 tons/day; and suspended sediment transport ranged from

0.109 to 2,213 tons/day. Over the range of measured discharges, suspended sediment accounted for the majority of the sediment transport with rates exceeding bedload transport by over an order of magnitude (USDA Forest Service undated).

- Main Fork Red River at its confluence with the South Fork Red River – The stream is on National Forest. Streamflow and sediment data were available from 1986 to 1999 and other information was collected for the study (painted rock movement and large bedload during high snowmelt flows, pebble counts, stream reach survey, and core samples). Stream discharges ranged from 9.88 cfs to 646 cfs; bedload transport ranged from 0.0 to 23.6 tons/day; and suspended sediment transport ranged from 0.02 to 194 tons/day. At the lowest discharge measure, suspended transport was about seven times that of bedload and at the highest measured discharge, it is about 1.5 times (USDA Forest Service undated).

- South Fork Red River at the confluences with the Main Fork Red River - The stream is on National Forest. Streamflow and sediment data were available from 1986 to 1999 and other information collected for the study was the same as for Main Fork Red River. Stream discharges ranged from 5.93 cfs to 458 cfs; bedload transport ranged from 0.0 to 22.4 tons/day; and suspended sediment transport ranged from 0.01 to 119 tons/day. Over the range of measured discharges, suspended transport accounted for the majority of the material in transport with approximately a four to six -fold difference in the rates (USDA Forest Service undated).

- Trapper Creek about 0.8 miles upstream of its confluences with the South Fork of Red River. The stream is on National Forest. Streamflow and sediment data were available from 1986 to 1997 and other information was collected for the study (pebble counts, stream reach survey, core samples). Stream discharges ranged from 1.69 cfs to 135 cfs; bedload transport ranged from 0.0005 to 15.1 tons/day; and suspended sediment transport ranged from 0.0045 to 27.8 tons/day. Over the range of measured discharges, suspended transport accounted for the majority of the material in transport, especially at lower discharges (USDA Forest Service undated).

Middle Fork Clearwater Watershed

- Lolo Creek, tributary to the Middle Fork Clearwater River, at Forest Service boundary near Greer, Idaho. The stream is on National Forest. Streamflow and sediment data were available from 1982 to 1997 and other information was collected for the study (pebble counts, stream reach survey, core samples). Stream discharges ranged from 26.8 cfs to 809 cfs; bedload transport ranged from 0.0110 to 14.1 tons/day; and suspended transport ranged from 0.03 to 58.4 tons/day. Over the range of measured discharges, suspended transport accounted for the majority of the material in transport (USDA Forest Service undated).

Three draft work plans were written for the Snake River Basin Adjudication: Cottonwood Creek in the lower part of the South Fork Clearwater Watershed; Lapwai Creek in the lower part of the Clearwater Watershed (11 miles east of Lewiston); and Lawyer Creek in the Clearwater Watershed, just below the confluence of the Middle Fork Clearwater and South Fork Clearwater. All three are largely on private land.

In the draft Cottonwood Creek work plans written for the Adjudication, it was found that sediment levels are an issue. Riparian tree and shrub removal, field plowing and channelization have modified most streams on agricultural land. This has resulted in channel erosion, channel destabilization, and sediment deposition. As the tributary streams flow from the prairie via the breaklands to the confluence of the South Fork Clearwater River, erosion of channels is common due to steeper gradients and altered upstream conditions. As these streams get closer to the valley floor, their gradients drop considerably, causing deposition of bedload sediment. This has resulted in aggraded channels. Analyses showed that to meet the total suspended TMDL at the mouth of Cottonwood Creek, the suspended sediment load needs to be reduced 60 percent during the period of January through May. Similarly, Red Rock needs a 64 percent reduction. Bedload modeling indicated that to stabilize the streambed at bankfull discharge, the streambed stability needs to be increased by approximately 46 percent (ISCC 2005a).

In the Lapwai and Lawyer Work Plans (ISCC 2005b, c) sediment was determined to need reduction for similar reasons as in Cottonwood Creek, particularly for cropland as it is the source of approximately 99 percent of the sediment over background levels.

Other Sediment Data

The PIBO Effectiveness Monitoring Program was initiated to determine whether PACFISH/INFISH management practices are effective in maintaining or improving the riparian conditions and to evaluate the effect of land management activities. Sampling started in 2001 and the second sampling rotation will begin in 2006 to provide data to describe changes in conditions. The sites were selected because they were thought to be the most likely locations that would show integrated effects from upstream management actions. There are several sites in each of the watersheds in the Clearwater River Basin where both physical and biological monitoring are done. The monitoring protocols and other information are available on line at:

http://www.fs.fed.us/biology/fishecology/emp/

and the data can be accessed on:

http://svinetfc2.fs.fed.us/pibo/.

There are also on-line data collected in the Clearwater River watersheds that are consistently collected in Idaho. There are USGS monitoring data on http://waterdata.usgs.gov/nwis and the IDEQ data collected for the 303(d) listing evaluations on:

http://mapserver.deq.state.id.us/Website/deqwaters/viewer.htm.

Both of these sites provide the data from individual site visits for streams monitored in Idaho.

6.4 MANAGEMENT PRACTICES AND RESTORATION PROJECTS

As noted in Section 5.1.5, approximately 45 percent of the Clearwater subbasin (not including the North Fork) is designated as having some degree of protected status; 29 percent of the subbasin is in designated wilderness. Management in these areas has virtually no potential to create sediment problems or to reduce sediment production from natural problem areas.

Overall, 63 percent of the subbasin is managed by the Forest Service or BLM under Forest Plans and Resource Management Plans (see Section 3.2.1). The Clearwater and Nez Perce National Forests are jointly revising their management plans, including customizing, but they are not expected to substantively change the protection provided by PACFISH and INFISH.

As noted in Section 5.1.4, the Upper Selway, Lower Selway, and Lochsa watersheds are almost entirely under National Forest management, the South Fork and the Middle Fork watersheds are 71 and 51 percent under Federal management (including BLM), respectively, and the Clearwater watershed is mostly in private ownership and only has 10 percent under National Forest management.

As a result of past landslides, the Forest Service has worked on identifying roads with high failure risks and either abandoning or obliterating them. They have also worked with the Nez Perce Tribe to obliterate old, unused roads and roads that are in danger of failing and damaging streams (Bugosh 1999).

The Idaho Forest Practices Act and its amendments constitute minimum standards for forest practices on forest lands in Idaho; the Act primarily affects forest practices on state and private lands, because Forest Service and BLM forest practices are more restrictive. It establishes SPZs around streams and limits practices within those SPZs. Skidding logs in or through streams is prohibited, but there is no prohibition against slash burning within SPZs. Harvest practices must retain at least 75 percent of existing stream shade and leave trees are designated by number, distance from stream, stream width, and tree diameter. Class I streams (including lakes and streams used for domestic water supply and/or are important for spawning, rearing or migration of fish) have a designated SPZ of the area encompassed by a slope distance of 75 feet on each side of ordinary high water marks. The Class II SPZ for streams that contribute flow to Class I streams is the area encompassed by a slope distance of

30 feet on each side of the ordinary high water mark. Streams that do not contribute flow to Class I streams have minimum SPZs of 5 feet.

BMPs have been published in the Idaho Agricultural Pollution Abatement Plan (Resource Planning Ltd. 2003) for agriculture (including grazing), but they are largely voluntary at this time. Improvements are generally implemented with willing landowners through the efforts of several agencies (e.g., soil and water conservation districts, Idaho Department of Fish and Game, Idaho Department of Water Resources), Nez Perce Tribe, and non-for-profit groups. The Clearwater Subbasin Management Plan (Ecovista 2003) includes general prioritization for watershed improvements to guide habitat improvement efforts on publicly and privately owned lands.

The Clearwater River Focus Program was created in late 1996 under the NPPC's Columbia River Basin Fish and Wildlife Program. The purpose of the program is to coordinate efforts to restore habitats in the Clearwater River watershed to meet the goals of the Council's fish and wildlife program. The ISCC and the Nez Perce Tribal Watershed Division co-coordinate the program. They have conducted restoration projects on private, state, Federal, and tribal lands. Major funding is BPA-approved through the NPPC. Other partners include the Forest Service, NRCS, soil conservation districts, private landowners, Idaho Department of Fish and Game, and the BLM. The projects funded include riparian fencing, riparian planting, road obliteration, culvert replacement, bank stabilization, sediment basins, off-site watering, and other.

The Clearwater Focus Program convened the Policy Advisory Committee, including the Nez Perce Tribe, and developed the Clearwater Subbasin Plan. The plan was developed as part of the NPPC's Columbia River Basin Fish and Wildlife Program and is used to help direct BPA funding of projects. The plan was locally organized and involved the major resource manager and government agencies. The planning included developing an assessment of the watershed to provide the background information to support the recommendations, an inventory of the management, existing resources, and ongoing work in the watershed, and a management plan with a vision for the Clearwater watershed, biological objectives, and strategies for reaching management goals (Clearwater Focus Program 2005).

In the Clearwater Assessment, sedimentation is cited as a primary limiting factor for the federally listed fish species in all assessment units, although it's most widespread in the Lolo/Middle Fork area and also problematic in most of the Lower Clearwater and South Fork areas. Sediment abatement activities in the watershed include road decommissioning, riparian fencing, implementing forestry BMPs, and implementing agricultural BMPs. While effectiveness of the programs is monitored in some cases, additional efforts are needed to understand the effectiveness (Ecovista et al. 2003). Appendix B to the Clearwater Inventory is a compilation of individual ongoing projects or programs that are related to habitat restoration and/or research, monitoring, and evaluation projects that address the management plan strategies and objectives (Objective S is to reduce sediments). The objective for each project (over 700 listed) is shown. Approximately one-third of the projects directly address the strategy to reduce sediments and many others would also indirectly affect sediments (Ecovista 2003).

6.5 SUMMARY OF PRELIMINARY CONCLUSIONS

Based on this review of available information, a few preliminary conclusions can be made regarding opportunities for sediment reduction. It appears that the most promising watersheds for reduction efforts would include the Clearwater, South Fork Clearwater, and Middle Fork Clearwater watersheds. In these watersheds, it appears that both agricultural lands and forest management land uses could be the focus of additional efforts at sediment control. Restoration of degraded riparian areas, projects to limit field erosion and delivery to streams in agricultural/grazing areas, and preventing road failures and minimizing road erosion in forest management areas appear to be the projects with the highest potential for success.

A large proportion of Federal lands, which dominate the Upper Selway, Lower Selway, and Lochsa watersheds, is in highly protected status, such as wilderness. Other Federal lands are managed under protective standards and guidelines. Although there appear to be several areas identified where natural landslides are a key factor, it is unlikely that much can be done to address these at the source.

7. SNAKE RIVER BASIN HELLS CANYON REACH – GEOGRAPHIC AREA

7.1 THE SETTING

7.1.1 Geography and Topography

The Snake River Hells Canyon Reach geographic area includes all drainages upstream of the mouth of the Clearwater River and downstream of Hells Canyon Dam, exclusive of the Salmon and Grande Ronde subbasins (Figure 5). It includes three 4th-field HUCs (referred to as watersheds) covering portions of Idaho, Oregon, and Washington and is 2,104 square miles in size (Table 21). Although the geographic area does not extend upstream of Hells Canyon Dam, flows in the Snake River within the geographic area include flows from the large drainage basin of more than 70,000 square miles upstream of Hells Canyon Dam (including most of southern Idaho and portions of Oregon, Washington, Wyoming, Nevada, and Utah).

Table 21. Size and Cataloging Unit Number for Watersheds within the Snake River Basin Hells Canyon Reach Geographic Area

Watershed Name	Cataloging Unit Number	Area (Square Miles)	Percent of Study Area
Hells Canyon	17060101	538	26
Imnaha	17060102	857	41
Lower Snake - Asotin	17060103	708	34
Total	**--**	**2,104**	**100%**

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

The Snake River generally flows in a northerly direction in the reach from Hells Canyon Dam to the mouth of the Clearwater River. In this reach, it forms either the border between Oregon and Idaho (southerly portion) or the border between Washington and Idaho (northerly portion). Major tributaries to this reach are the Imnaha River (which enters the Snake from the west side near the downstream end of the lower Hells Canyon watershed), the Salmon River (which enters the Snake from the east side at the lowest end of the Hells Canyon watershed), the Grande Ronde River (which enters the Snake from the west side in the middle of the Lower Snake-Asotin watershed), and Asotin Creek (which enters the Snake from the west side near the downstream end of the Lower Snake-Asotin watershed) (Figure 5). In addition, there are other smaller tributaries located throughout this reach that flow directly into the mainstem Snake River.

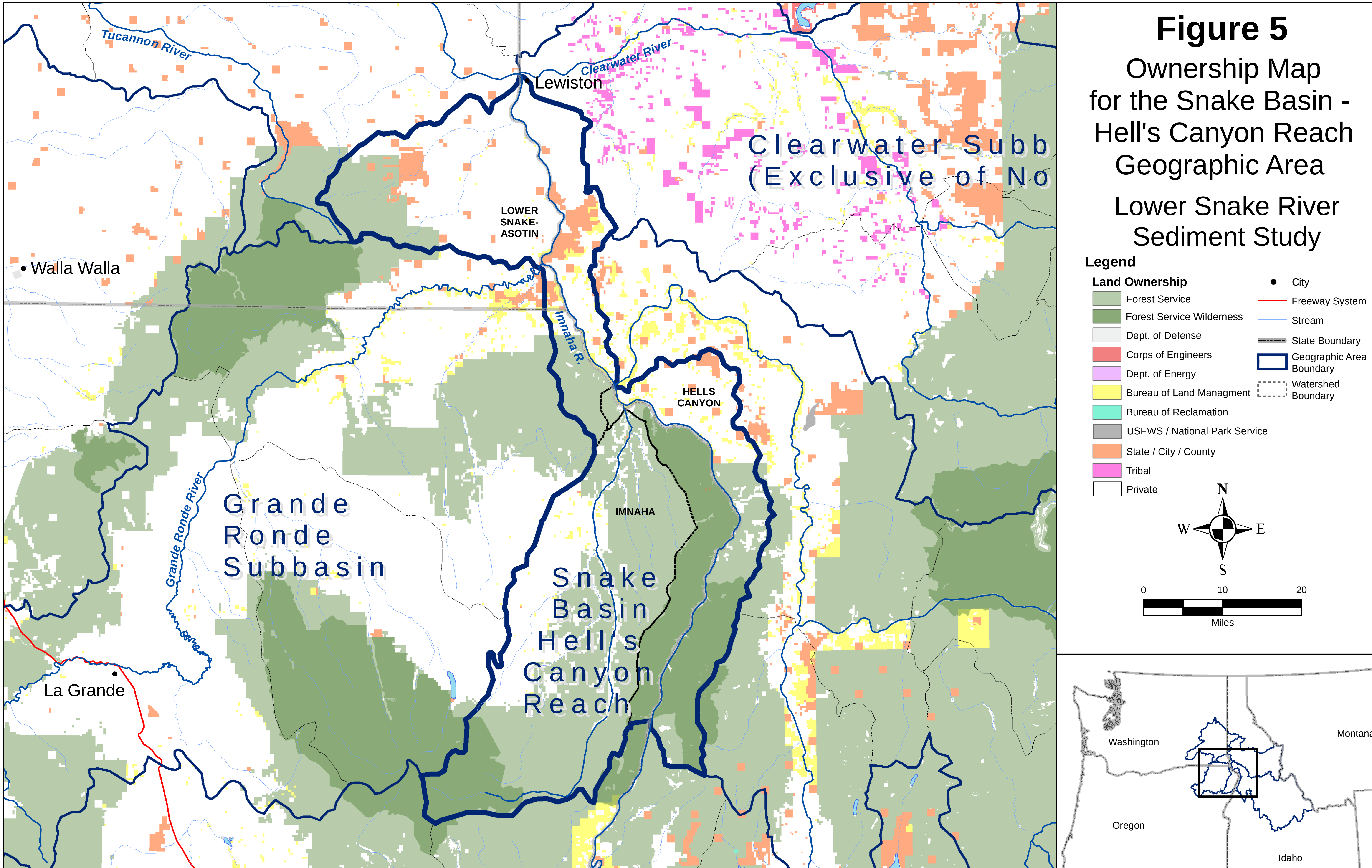


Figure 5
Ownership Map for the Snake Basin - Hell's Canyon Reach Geographic Area
Lower Snake River Sediment Study

P:\projects_2005\Snake_River_Sediment\maps\salmon_ownership.mxd

The mainstem Snake River within the Hells Canyon watershed flows through a narrow, steep-sided, V-shaped canyon averaging 5,500 ft. deep that is entrenched in erosion-resistant basalt and metamorphic rock. The main formative agent for Hells Canyon was the "catastrophic flood of water from Lake Bonneville" that occurred approximately 14,500 years ago. Peak flood flows during this event have been estimated to be about 20 million cfs [Idaho Power Company (IPC) 2003]. Since the Bonneville Flood, the Hells Canyon section of the Snake River is considered to be highly stable.

The Imnaha River flows in a generally northerly direction, paralleling the Snake River (Figure 5). The primary tributaries (Big and Little Sheep creeks) originate in the Wallowa Mountains in Oregon.

Asotin Creek originates in the Blue Mountains of Oregon and flows in a generally northeasterly then easterly direction to its confluence with the Snake River in Washington State. Key tributaries to the mainstem of Asotin Creek include George Creek, Pintler Creek, Charley Creek, North and South Forks of Asotin Creek, and Lick Creek (tributary to the North Fork).

Because of the geographic division of many of the studies, the following breakdown of areas is used in most of the discussions that follow, rather than the 4th-field HUC watershed breakdown:

- Mainstem Snake River and Local Tributaries in the Reach from Hells Canyon Dam downstream to mouth of the Clearwater River (exclusive of the Imnaha, Salmon, and Grande Ronde Rivers, and Asotin Creek)
- Imnaha River Subbasin
- Asotin Creek Subbasin

7.1.2 Hydrology

The climate in this region is influenced by predominantly westerly winds from the Pacific Ocean and the Cascade Mountains. The region is generally characterized as temperate continental and dry. Most precipitation occurs during short intense summer storms and longer, milder winter storms. During the summer period, the area is influenced by marine air that moves into the area from the Pacific Ocean. In the winter, the area is influenced y Arctic air masses that spill over the Rockies. Local weather patterns may also be affected by the Wallowa Mountains and the Blue Mountains to the west of the Snake River.

A large portion of the streamflow in this area originates from snowpack or large rain-on-snow events that historically have resulted in major flooding. For example, major floods that caused substantial damage to private property and riverine habitat occurred in this region in December 1964, January 1965, January 1974, December 1996, and January 1997 (Kuttle

2002). In contrast, flows from areas upstream of Hells Canyon Dam, are controlled by numerous water control structures (e.g., dams or diversions for hydropower, irrigation, municipal and industrial uses, recreation, and other off-channel uses). As a result, the runoff pattern from upstream is highly regulated.

7.1.3 Land Cover

In general, this region was originally covered with prairie and canyon grasslands and shrub-steppe vegetation at low to mid-elevations. Forest became more prominent as elevation increased and in proximity to either the Wallowa or Blue Mountains (Kuttle 2002). Table 22 describes the present-day vegetation and land cover/use in this reach.

Higher elevations tend to be forested or geologically "young" areas, whereas the lower elevations are mainly used for agriculture (i.e., cropland or livestock production). An exception to this is the low elevations within Hells Canyon, which are non-agricultural and typically grasslands. The higher elevations of Hells Canyon watershed are mostly forested.

The Imnaha watershed higher elevations are also mostly forested, but the watershed also contains many grasslands and some agricultural areas. The Lower Snake-Asotin watershed is characterized by grasslands and agricultural lands at lower elevations and evergreen forests at higher elevations (Asotin County Conservation District 2004).

Table 22. General Land Cover Percent by Watershed within the Snake River Basin Hells Canyon Reach Geographic Area (percent of total watershed area)

Watershed Name	Agricultural and Urban	Herbland	Shrubland	Early-seral Forest	Mid-seral Forest/ Woodland	Late-seral Forest	Other[1/]
Hells Canyon	9%	30%	3%	28%	17%	13%	0%
Imnaha	10%	30%	3%	41%	10%	5%	2%
Lower Snake – Asotin	47%	26%	2%	13%	12%	0%	0%
Total	**22%**	**28%**	**2%**	**28%**	**13%**	**6%**	**1%**

[1/] Riparian, Alpine, Water, Rock, Barren
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

7.1.4 Land Ownership

Table 23 presents the land ownership for each watershed in the geographic area. As can be seen, the majority of the geographic area is managed by the Forest Service, with a limited acreage by the BLM. The Hells Canyon and Imnaha watersheds are each over 70 percent in Federal ownership. Private lands dominate the Lower Snake-Asotin watershed, but Federal ownership covers 25 percent and Idaho and Washington state lands cover 8 percent combined.

Table 23. Land Ownership by Watershed within the Snake River Basin Hells Canyon Reach Geographic Area (percent of total watershed area)

Watershed Name	Private	Tribal	State	National Forest (non-Wilderness)	National Forest Wilderness	BLM
Hells Canyon	23%	-	2%	21%	52%	1%
Imnaha	28%	-	-	60%	11%	<1%
Lower Snake – Asotin	66%	-	8%	23%	-	2%
Total Basin[1\]	**40%**	**0%**	**3%**	**38%**	**18%**	**1%**

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

7.1.5 Land Use

Approximately 18 percent of the geographic area is in designated wilderness. The wildernesses include the Hells Canyon Wilderness, primarily in the Hells Canyon watershed, and the Eagle Cap Wilderness in the Imnaha watershed. In addition, a large portion of the lands are managed as Federal Wild and Scenic Rivers, and National Recreation Areas. Private ownerships are largely dedicated to croplands or grazing.

Road densities are very low in the Hells Canyon watershed, slightly higher in the Imnaha watershed, and moderate in the Lower Snake-Asotin watershed, where the majority of the roads are rural roads and farm access roads (Table 24). Over 70 percent of the Hells Canyon watershed has road densities less than 0.1 mile/square mile. This density class represents 55 percent for the Imnaha watershed, but only 20 percent of the Lower Snake-Asotin watershed.

Table 24. Road Density Predicted Classes by Watershed within the Snake River Basin Hells Canyon Reach Geographic Area (percent of total watershed area).

Watershed Name	Road Miles per Square Mile					
	0 – 0.02	**0.02-0.1**	**0.1-0.7**	**0.7-1.7**	**1.7-4.7**	**>4.7**
Hells Canyon	70%	2%	5%	17%	5%	1%
Imnaha	51%	4%	7%	22%	14%	2%
Lower Snake – Asotin	15%	5%	27%	37%	11%	5%
Total Basin	**44%**	**4%**	**13%**	**26%**	**11%**	**3%**

Source: Map 3.28, Volume II, in Quigley and Arbelbide (1997). Data used to form these classes was statistically extrapolated from sampled 6th-field HUC road data.

7.2 OVERVIEW OF SEDIMENT TRENDS AND HISTORIC CHANGE

Table 25 presents some ratings developed by Interior Columbia Basin Ecosystem Management Project (Quigley and Arbelbide 1997), which can be used as overall indices of the relative level of disturbance in each watershed within the geographic area. The measures relate to the degree of hydrologic disturbance in forest and rangeland environments (based on the level of surface mining, dams, cropland conversion, and roads) and the degree of riparian disturbance in rangeland environments (based on the sensitivity of streambanks to grazing and the sensitivity of stream channel function to the maintenance of riparian vegetation).

Based on these ratings, some broad generalizations can be made. The overall level of disturbance is low to moderate in the Hells Canyon and Imnaha watersheds, depending on the category. In contrast, the Lower Snake-Asotin watershed has a moderate to high disturbance rating, depending on the category.

Table 25. Hydrologic Disturbance Rating of Forest and Rangeland Environments and Riparian Disturbance Rating of Rangeland Environments Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Snake River Basin Hells Canyon Reach Geographic Area

Watershed Name	Hydrologic Disturbance Rating of Forest Environments	Hydrologic Disturbance Rating of Rangeland Environments	Riparian Disturbance Rating of Rangeland Environments
Hells Canyon	Moderate	Low	Moderate
Imnaha	Low	Low	Moderate
Lower Snake – Asotin	High	High	Moderate

Source: Maps 2.34, 2.35, and 2.36, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

Snake River Upstream of Hells Canyon Dam

The Snake River upstream of the Hells Canyon Dam includes lands in Idaho, Oregon, and small portions of Wyoming, Nevada, and Utah. In support of its application for a new Federal Energy Regulatory Commission license for the Hells Canyon Complex (HCC – this includes the Hells Canyon Dam at river mile [RM] 247.6, Oxbow Dam at RM 272.5, and Brownlee Dam at RM 284.9), IPC reviewed the history and current status of sediment transport from upstream areas into the reach downstream of Hells Canyon Dam (to the confluence with the Salmon River). The information in the application provides a detailed accounting of the investigations and findings of the study (IPC 2003).

The following briefly summarizes IPC's (2003) findings regarding trends and historic change:

- Beginning in the early 1800s, major sources of sediment in this area (from anthropogenic [human] activities) included trapping, mining, forest management, fires, and agricultural development. During the 1900s, further growth (particularly in agriculture) continued to add to this sediment load (IPC 2003).
- Numerous reservoirs have been constructed on the mainstem Snake River and along its tributaries since the early 1900s. For example, there are 13 major facilities on the mainstem Snake River between Jackson Dam in Wyoming and the HCC. These are used to store water for irrigation, flood control, hydropower, or some combination of the three. IPC also indicates that there are an additional 35 facilities (each with at least 5,000 acre-feet of storage capacity) located along the Snake River tributaries upstream of Brownlee Reservoir (IPC 2003).
- Primary sources of sediment occur in the upper parts of watersheds and particularly in the Idaho Batholith area (Boise River and Payette River watersheds). Sediment input to the lower Snake River from these areas has been largely cut off by the reservoirs (IPC 2003).
- The HCC essentially prevents all sediments in the Snake River upstream of the HCC (sand size and larger) from traveling to areas downstream. This conclusion by IPC is based on evaluation of sources upstream of Brownlee Reservoir and tributaries to the reservoirs of the HCC (IPC 2003).

Based on the above conclusions, the input of any sediment from areas upstream of Hells Canyon Dam is essentially negligible and this trend is expected to continue. The only exception might be fine sediment that can remain in suspension during higher flows.

Snake River Downstream of Hells Canyon Dam

Hells Canyon has steep continuous slopes that, in some areas, extend over a mile in elevation from the river to the crest of the canyon. Information on erosion characteristics and processes of soils in the canyon is limited. Soils in the area have been identified as potentially highly erodible. However, surface erosion processes are not common because of the protective cover of grassland and shrub-steppe vegetation as well as forest canopies on many north-facing side slopes (Ecovista 2004b). Historical human disturbances in the canyon affecting sediment have been relatively limited. The main erosion processes taking place in the canyon are various forms of mass wasting, with rock and debris flows being most prevalent (Ecovista 2004b).

Imnaha Subbasin

The primary source of sediment in the basin is roads, mainly along the mainstem Imnaha (Ecovista 2004a). Additional sediment sources include livestock grazing, rural home sites, pasture creation, and other activities that have modified soil and vegetation characteristics. The upper watershed has high sedimentation rates because of the instability of the barren granite mountain peaks. Debris flows and other processes of mass wasting, which are commonly triggered by thunderstorms or rain-on-snow events, are primary sources of sediment input to downstream areas (BLM 1993).

The Forest Service has closed, decommissioned, relocated, and restricted access on several roads or road segments to decrease sedimentation. For example, in 1990 and 1991, 6.4 miles of road were closed, 3 miles were obliterated, and 26 acres of roadbed were seeded (USDA Forest Service 1998). In addition, a 5-mile section of USFS Road 3900 was relocated or reconstructed. Other measures include seasonal road use restrictions and increased road maintenance. These measures will reduce sediment inputs in the future.

The Imnaha Subbasin Plan (Ecovista 2004a) provides information about historic changes and trends in grazing activities. In the 1800s and early 1900s, there was intense competition for grass in the Imnaha River Subbasin. This reached a peak in the 1930s when most riparian areas lost their native grasses and woody vegetation. This resulted in excessive erosion of soils into stream channels during spring runoff or following summer storm events (Wallowa County and Nez Perce Tribe 1993).

Due to concern about the deteriorated stream conditions, local groups, with the assistance of the Forest Service collaborated in reducing grazing in the basin. Improvement has occurred, mainly by passage of private and Federal land regulations in 1994, and again in 1997, that set forth certain rules governing land use activities and developments that are designed to stabilize the watershed and reduce sediment inputs (Ecovista 2004a).

Fires have also contributed to increased sheet and rill erosion in the Imnaha River basin. These are unpredictable events that may occur in the future. Areas affected may take several decades to recover, with highest sediment inputs occurring soon as the fire and decreasing as vegetation returns and streams stabilize.

Agriculture and timber harvest are identified as other additional sediment sources in this subbasin. Increased regulatory constraints for these activities (e.g., establishment of stream buffers along streams and BMPs for agriculture) should reduce sediment inputs in the future. The Subbasin Plan identifies the Wallowa Valley Improvement Canal (WVIC) between RM 31.9 and RM 33.7 on Big Sheep Creek as a contributor to changes in sediment availability and transport capacity due to decreased flows.

Present-day conditions in the Imnaha River subbasin are generally good relative to other subbasins in the Columbia River Basin (Ecovista 2004a). Reasons for this include the high percentage of the basin that is protected under management of the Forest Service and the general improvement in habitat conditions over the past 20 to 30 years resulting from better land management practices and reduced levels of road construction, logging, and grazing.

Asotin Subbasin

This summary is based on the key findings of the Asotin Subbasin Plan (Asotin County Conservation District 2004) that address sediment sources and transport in the Asotin subbasin. Historically, Asotin Creek had a less severe gradient, a meandering flow pattern, and well developed floodplain connections. In contrast, much of Asotin Creek and its tributaries have been straightened, diked, or relocated. Farming, timber harvesting, and urbanization have changed the runoff patterns in the Asotin Creek subbasin. Other contributors to these conditions include modification of the riparian zone, including tree removal, road building, grazing, soil compaction, and flood control projects or stream channel straightening. Major flooding events (e.g., in 1997) have substantially altered the riparian vegetation. Stream channel instability in the Asotin Creek subbasin includes channel widening, downcutting, vertical cut banks, and excessive gully development. Livestock grazing in the Asotin Creek subbasin is a major land use, starting in the early 1800s. The Forest Service implemented regulations on its lands in 1929 with the Asotin Allotment, which was followed by the Peola-Pomeroy allotment in 1939.

The Subbasin Plan characterized the current trends in habitat in the Asotin subbasin as improving. The primary reason cited for this improvement is the implementation efforts of the Asotin Creek Model Watershed Plan. Additional improvement should occur as a result of the subbasin planning efforts.

7.3 SEDIMENT SOURCES AND YIELD

7.3.1 Overview Studies of Erosion and Mass Wasting Hazards

In this section, ratings and other results from a number of overview studies that were conducted across the entire Columbia River basin or over larger areas are presented for perspective and comparison purposes. The methods behind these studies are summarized briefly below and in more detail in Section 4.1.

The Interior Columbia Basin Ecosystem Management Project conducted by the Forest Service and the BLM (Quigley and Arbelbide 1997) developed various soil erosion, mass failure, and sediment hazard ratings for nonpoint sources for each watershed, relative to all Columbia Basin watersheds. The key ratings are shown for the Snake River Basin – Hells Canyon Reach geographic area in Tables 26 and 27.

Table 26. Soil Erosion, Mass Failure, and Sedimentation Measures Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Snake River Basin Hells Canyon Reach Geographic Area .

Watershed Name	Surface Soil Erosion Hazard	Earth Flow Hazard	Debris Avalanche Hazard	Sediment Delivery Potential	Sediment Delivery Hazard
Hells Canyon	High	Mod - High	High	High	High
Imnaha	High	Mod - High	High	High	High
Lower Snake – Asotin	High	Low - Mod	Low - Mod	High	High

Source: Maps 2.10, 2.11, 2.12, 2.13, and 2.15, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

Table 27. Road Erosion Hazard and Road Sediment Delivery Hazard Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Snake River Basin Hells Canyon Reach Geographic Area

Watershed Name	Road Erosion Hazard	Road Sediment Delivery Hazard
Hells Canyon	Low	High
Imnaha	Low	Mod - High
Lower Snake – Asotin	Mod - High	High

Source: Maps 2.16 and 2.17, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

NMFS (Baker et al. 2005) has developed two draft models for estimating increases in erosion rates relative to natural levels. Based on this study, erosion rates in the Hells Canyon watershed are mostly in the range of 1 to 2 times historical rates, except in the small northern portion that is mostly private lands where erosion rates are estimated at 2 to 3 times historical rates. Erosion rates for the Imnaha watershed are also mostly estimated at 1 to 2 times historical; however, the western edge of private lands is estimated at mostly in the range of 3 to 8 times historical. The Lower Snake-Asotin watershed is the most variable, with rates ranging from 1 to 2 times historical in a few small subwatersheds to 7 to 9 times historical in several low elevation agricultural areas.

The USGS developed a landslide overview map (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas which are susceptible to landsliding in the conterminous United States. Within the geographic area, there are no areas mapped as having a moderate or high incidence of past landslides or susceptibility to future landslides, except for an area that barely enters the Hells Canyon watershed along its far eastern edge.

A NRCS analysis of cropland for 1997 in the conterminous United States found that the geographic area had no areas of highly erodible cropland and no areas of highly erodible or non-highly erodible cropland with excessive erosion above the tolerable soil erosion rate, except for some areas in the lower elevations of the Lower Snake-Asotin watershed (NRCS 2000).

7.3.2 Specific Studies within the Geographic Area

Upstream of Hells Canyon Dam

The IPC studies of this reach evaluated potential sediment inputs from upstream of the Brownlee Reservoir and potential inputs from tributaries to the HCC reservoirs. IPC concluded that the heavily armored streambed (both above and below the HCC) demonstrates that the sediments stored in the bed are generally not available for transport or geomorphic processes. Findings by IPC (2003) include:

- HCC prevents essentially all of the sand size and larger sediment in the Snake River upstream of the HCC from traveling to the Hells Canyon reach of the Snake River.
- More than 96 percent of the material trapped in Brownlee Reservoir is fine sand (or smaller) and therefore, smaller than the majority of material found in the sandbars in Hells Canyon.
- Brownlee Reservoir has trapped about 62,000 acre-feet of sediment (estimated); an average of 1,550 acre-feet per year during the 40-year period between when Brownlee Dam was closed in 1958 and a bathymetric survey was completed in 1998. [To put this volume in perspective, this converts to nearly 2.4 million tons per year, assuming a unit weight of deposited sediments of 70 lbs per cubic foot, which is slightly higher than the 2.3 million tons/year measured in the USGS study for the Snake and Clearwater above Lewiston (Jones and Seitz 1980)].

Snake River Downstream of Hells Canyon Dam

Ecovista (2004b) prepared a subbasin assessment for the Snake Hells Canyon subbasin, which included an assessment of multiple attributes such as land use and cover, water quality, human disturbances, and limiting factors to production of anadromous salmonids. This subbasin plan was used extensively in describing the sediment characteristics for this area.

A large portion of the lands adjacent to the Snake River between Hells Canyon Dam and the confluence with the Salmon River is managed by the Forest Service, either as a designated Wild and Scenic River, Hells Canyon National Recreation Area, Hells Canyon Wilderness, or as general National Forest System lands (Figure 5). Overall, it is anticipated that sediment management practices under these designations will result in sediment inputs to the Snake River reach downstream of HCC at either present or lower levels.

As previously indicated, information on sediment sources or transport in the Hells Canyon reach is very limited (Ecovista 2004b). The most extensive work was conducted by IPC for its application for a new Federal Energy Regulatory Commission license (IPC 2003). In its application, IPC reported on studies that evaluated sediment inputs to the reach of the Snake River downstream from HCC from sources other than those upstream of Hells Canyon Dam. This included an evaluation of potential sediment input from tributaries, sandbars, hill slopes/terraces, and gravel bars/bedload.

The following summarizes IPC's findings for each of these areas. It also includes studies conducted by other sources, as noted.

Local Tributaries Upstream of Salmon River Confluence

Nearly all "fish-bearing" tributaries to the Snake River in the Hells Canyon National Recreation Area have high water quality, with good streamside cover and little streambank instability (Ecovista 2004b). IPC evaluated the sediment load from 17 tributaries (not including the Salmon or Imnaha Rivers) in a study area from Hells Canyon Dam downstream to near the confluence with the Clearwater River. Fifteen of these tributaries are upstream of the Salmon River because IPC felt that the Salmon River provides significant amounts of sediment, which mask any potential effects of sediment from sources upstream of this major tributary. Two other tributaries studied (Cook Creek and Cherry Creek) are immediately downstream of the confluence with the Salmon River.

In general, IPC described the 17 tributaries as having "steep slopes, relatively small drainage areas, and limited groundcover". With these conditions, IPC indicated "sediment conditions would be expected to be high". Four of these tributaries (Deep Creek, Getta Creek, Wolf Creek, and Divide Creek are listed under Section 303(d) for sediment. The TMDLs for these listings were due for completion by December 31, 2005.

For the tributaries evaluated, IPC did not identify specific sources of sediment or trends. IPC did, however, develop estimates of sediment input from each of the 17 tributaries. These estimates were based on field sampling and modeling results.

IPC (2003) determined that the two largest relative sources of sediment were Granite Creek and Sheep Creek, which are near the upper end of the study area. However, habitat conditions in these tributaries are less limited than in other tributaries because they originate in wilderness areas (Ecovista 2004b).

The studies by IPC (2003) made the following conclusions about input from the tributaries:

- The tributaries between the HCC and the Salmon River (not including the Imnaha River drainage) account for an average sediment yield of 8.60 million tons per year. The same calculations for sand and spawning-size gravels, respectively, are 1.44 and 4.14 million tons per year. (Note: This number does not agree well with the monitoring performed by the USGS (1980) which indicated that the sediment load for this reach, including the Salmon and Grande Ronde, was 1.76 million tons per year.).
- Tributaries in Hells Canyon not affected by HCC can supply sediment in the size range useful for maintaining sediment-related features such as sandbars and spawning sites in Hells Canyon.
- From visual observations, it appears that these tributaries have supplied sediment to the Snake River in Hells Canyon in recent years under current hydrologic conditions.
- The sediment is supplied directly from the tributaries during peak-flow events that occur on relatively short (geologically) time scales (tens to hundreds of years).

Local Tributaries Downstream of Salmon River Confluence

Tributaries downstream of the confluence of the Snake and Salmon Rivers have been described as degraded by road construction, timber harvest, development in riparian areas and floodplains, agriculture, livestock grazing, mining, recreation, and water uses. As a result, these lands have reduced water quality and elevated levels of sediment (Ecovista 2004b).

The Asotin Subbasin Plan (Asotin County Conservation District 2004) primarily addresses the Asotin Creek watershed. However, it also includes two creeks that flow directly into the Snake River downstream of the Salmon River. These are Tenmile and Couse Creeks. The Asotin Subbasin Plan indicates that little technical information is available for either creek.

The Limiting Factors Analysis report prepared by Kuttle (2002) indicated that sediment load and habitat diversity were problems in the Tenmile Creek watershed. This may improve in the future, however, because most of this stream is included the CREP. The Subbasin Plan recommends that when the stream buffer portion of this program is completed, efforts should be focused on upland areas to further reduce sediment to Tenmile Creek.

Couse Creek is "thought" to be limited by sediment loads and lack of habitat diversity (Kuttle 2002), but little technical information is available. Crouse Creek is not a priority in the Asotin Subbasin planning process, but is recommended for future consideration. However, one specific project implemented by the Asotin County Conservation District, landowners, and the NRCS involved fencing of over 8 miles of stream to restore riparian buffers. The project was funded by the CREP, BPA, and WDOE (WDOE 2005).

There are also small drainages on the east side of the Snake River that the IDEQ includes in its designation of the "Asotin – Lower Snake River Subbasin". One of these drainages is Tammany Creek. It is currently listed under Section 303(d) for excessive sediment. A TMDL has been developed for this drainage (IDEQ 2001). This TMDL is noteworthy because the Tammany Creek drainage likely represents several similar small local drainages in the lower elevations of the Asotin and nearby subbasins.

Following is a brief overview of the Tammany Creek drainage and the TMDL actions.

Watershed Description: Tammany Creek originates in the farmlands southeast of Lewiston and flows in a predominantly northwesterly direction to where it joins the Snake River. The creek is approximately 13 miles long and includes intermittent and perennial channels. The watershed is approximately 35 square miles and is predominantly agricultural land including both cultivated crop and livestock range uses (IDEQ 2001). The stream channel varies from well-developed floodplains to highly entrenched channels. The IDEQ indicates that the highly entrenched channels are particularly difficult problems for the control of instream sediment loading.

Sediment Sources: Sediment sources within the Tammany Creek watershed are sheet and rill erosion from crop and grazing lands, pasture land surface runoff, unpaved roadway runoff, rural development activities, animal feeding operations, wildlife stream bank damage, and direct stream bank erosion. The primary sediment sources have been identified as sheet and rill erosion, surface runoff from rural developments and stream bank erosion. The sediment sources are considered non-point sources (IDEQ 2001).

Through a combination of field surveys, water quality data analysis, and modeling of hydrologic and erosion processes, it was determined that sediment loading in Tammany Creek is above background levels by almost 3,000 tons per year and that this excess occurs from December through June during periods of higher flows. Mean monthly flows range from 0.48 cfs in August to 2.50 cfs in April. Therefore, even though this is a very small stream, it does contribute to the overall sediment input to the Snake River.

Management Plans: Sediment reductions need to occur in Tammany Creek to meet Idaho State Water Quality Standards and the requirements of the TMDL. The TMDL planning process is under development for inclusion in an existing PL-566 watershed project. This existing project is being implemented by the NRCS and the Nez Perce Soil and Water Conservation District. The project will be monitored by the Idaho Association of Soil Conservation Districts. The Association will be monitoring the effectiveness of BMPs implemented as part of the PL-566 project and the TMDL. The Association will report information generated to the watershed advisory group. The IDEQ also has reporting and monitoring responsibilities through the Idaho's reporting requirements under Sections 305(b) and 303(d) of the Federal CWA.

Conclusions and Recommendations: Although Tammany Creek is a very small drainage, it does carry sediment loads that are discharged into the Snake River very near the Lewiston area. These inputs are from non-point sources of discharge that are being dispersed across the drainage. An implementation plan has been initiated and will include BMPs and other aspects of the existing PL-566 project.

The inclusion of Tammany Creek and similar small drainages in this evaluation is likely very important because of the dispersed and cumulative effects that this drainage represents. It is also important to note that a TMDL has been developed and an implementation plan initiated for reducing sediment loads. Over time, if this plan succeeds, sediment reductions should occur. The Corps should track the implementation planning process and any monitoring and evaluation studies that may occur as a result of this process.

Sandbars, Hillslopes/Terraces, and Gravel Bar/Bedload Movement:

IPC evaluated non-tributary sediment input from sources within Hells Canyon downstream of Hells Canyon Dam (e.g., hillslopes/terraces and gravel bar/bedload movement) and the deposition or erosion of sandbars and banks during the period of 1997 to 2000 (IPC 2003).

Using X-ray diffraction, field studies, sediment transport modeling, and other approaches, IPC (2003) found that:

- Course sediment and spawning gravels in the streambed are of local origin and were not transported from upper parts of the basin.
- The heavily armored bed below HCC demonstrates that the sediments stored in the bed are generally not available for transport or geomorphic process.
- Transport mechanisms of the mainstem river upstream of the HCC are insufficient to mobilize and transport material such as that found in the riverbed of the Hells Canyon reach.
- River banks in Hells Canyon are very stable, with only 2 percent showing evidence of erosion.
- Terraces along the canyon are generally stable for the large majority of flows but may become unstable when subjected to rapid drawdown of water surface elevations following major flood events.
- Sandbars respond in size and shape to varying flows and sediment loads in the river. Each sandbar in the study reach experiences erosion. Possible reasons suggested for erosion of the sandbars were jet boats (and their associated effects of wave action and jet pumps) and foot traffic associated with landing of boats. Overall, however, the number of sandbars in the Hells Canyon Reach has been relatively stable from 1973 to 1997.

Imnaha Subbasin

The Imnaha Subbasin Plan (Ecovista 2004a) provides key information about sediment sources and transport in the Imnaha River subbasin. The Plan provides extensive details on natural resource attributes (e.g., soils, elevations, erosion) and land use (e.g., National Forest, cattle allotments, streams, hydrology). This document and its supplements were the primary sources of general information about this area.

The Imnaha Subbasin Plan (Ecovista 2004a) describes the general features of the subbasin as:

- The narrow river terraces along the banks of the Imnaha River and its major tributaries are primarily formed from alluvial deposits. The sources of these deposits are river rock from upstream, colluvial basalt from the canyon side slopes, and Mazama ash (volcanic source) and windblown silt mixed in with the soils that formed on the river terraces. The terraces are located in the central part of the Imnaha River and lower Big and Little Sheep creeks. The main channels in these areas have some ability to meander through the unconsolidated sediment. About 84 percent of the riverbanks in the subbasin, including these terraces, are stable due mainly to vegetation and course sediment (Ecovista 1994a).

- The primary source of sediment in the basin is roads, mainly along the mainstem Imnaha. Additional sediment sources include livestock grazing, rural home sites, pasture creation, and other activities that have modified soil and vegetation characteristics.

- The upper watershed has higher sedimentation rates because of the instability of the barren granite mountain peaks. Debris flows and other processes of mass wasting, which are commonly triggered by thunderstorms or rain-on-snow events, are primary sources of sediment input to downstream areas (Ecovista 2004a).

The Imnaha Subbasin Plan (Ecovista 2004a) identifies naturally occurring unstable barren granite mountain peaks in the upper portion of the subbasin as being high sediment sources. These are natural processes that may or may not continue into the future. They are exacerbated by thunderstorms or rain-on-snow events that trigger debris flows or other forms of mass wasting. Similarly, bank erosion is accelerated by these same events. One of the largest single sediment input events in recent years was from landslides in the wilderness areas of the headwaters during the 1997 flood.

The Subbasin Plan characterized Big Sheep and Little Sheep creeks, two major tributaries in the Imnaha River Basin, as “geomorphologically young systems with active erosion in the oversteepened headwalls of the Wallowa Mountains.” Snow avalanches and debris flows occur frequently contributing sediment and large woody material to downstream reaches (Ecovista 2004a). These natural processes are likely to continue.

The Subbasin Plan indicates “roads represent the primary source of sediment in the subbasin, and specifically within the mainstem Imnaha.” The large flood event in 1997 caused considerable disruption of the road infrastructure, which resulted in the needed for major repairs and reconstruction. Repair work emphasized the need to “fortify” the structures to protect against similar future flood events. This has resulted in “detrimental” changes to the channel morphology and hydraulics in some areas.

A number of isolated sediment studies have been conducted in the Imnaha River Basin. The Imnaha Subbasin Plan indicates that fine sediment problems are localized. The Plan attributes this to the stability of the system, which is characterized by non-erodible Columbia River basalt, metamorphosed volcanic rock, coarse alluvium, and hydrophilic ash that overlies upland areas. The Forest Service (Ecovista 2004a) found that forest fires and timber harvest accelerated sheet and rill erosion in the Big Sheep Creek watershed.

The Forest Service has also documented other incidents of sediment input into the Imnaha River (Ecovista 2004a). These incidents include streambank erosion, gully erosion, road development and grazing. The 1997 flood event and a thunderstorm in August 1992 both resulted in landslides in the Imnaha subbasin. The Forest Service believes that this material will move in “pulses” through the subbasin until stabilized by large woody debris, riparian vegetation, or channel processes that bring the materials in to equilibrium with stream flows. The Subbasin Plan indicates that many of the headwater tributaries have high gradients and, combined with effects from land use activities, these areas produce a very flashy flow regime that is often capable of mobilizing bedload.

As part of the subbasin planning process, an Ecosystem Diagnosis and Treatment (EDT) analysis was conducted (Mobrand Biometrics 2006). This process evaluates existing information and knowledge of local biologists to determine the current state of a watershed and helps to prioritize areas for protection or restoration of fish habitat. The results of this analysis are presented in the Subbasin Plan. The Subbasin Plan identifies a need to develop a subbasin-wide database to facilitate monitoring and evaluation of sedimentation trends.

Asotin Subbasin

The Asotin Subbasin Plan (Asotin County Conservation District 2004) provides key information about sediment sources and transport in the Asotin River subbasin. The plan and its supplements were primary sources of information for this section because the information is relatively recent and provides a good perspective on sediment in the basin.

Key findings in the Asotin Subbasin Plan that address sediment sources and transport include the following:

- The Asotin Creek Basin consists of basaltic rocks that are overlain by highly erodible fine-grained loess soils. The underlying bedrock in the basin is tilted slightly to the north and east which results in streams that are cut down and form very steep and generally narrow, V-shaped canyons (Asotin County Conservation District 2004).
- Historically, Asotin Creek had a less severe gradient, a meandering flow pattern, and well developed floodplain connections. In contrast, much of Asotin Creek and its tributaries have been straightened, diked, or relocated (Asotin County Conservation District 2004).
- Farming, timber harvesting, and urbanization have changed the runoff patterns in the Asotin Creek Basin. Other contributors to these conditions include modification of the riparian zone, including tree removal, road building, grazing, soil compaction, and flood control projects or stream channel straightening (Asotin County Conservation District 2004).
- Major flooding events (e.g., in 1997) have substantially altered the riparian vegetation (Asotin County Conservation District 2004).
- Stream channel instability in the Asotin Creek Basin includes channel widening, downcutting, vertical cut banks, and excessive gully development (Asotin County Conservation District 2004).
- Livestock grazing in the Asotin Creek Basin was a major land use, starting in the early 1800s. The Forest Service implemented regulations on its lands in 1929 with the Asotin Allotment, which was followed by the Peola-Pomeroy allotment in 1939 (Asotin County Conservation District 2004).

As part of the subbasin planning process, an EDT analysis was conducted. This process evaluates existing information and knowledge of local biologists to determine the current state of a watershed and helps to prioritize areas for protection or restoration. The results of this analysis are presented in the Subbasin Plan.

7.4 MANAGEMENT PRACTICES AND RESTORATION

Upstream of Hells Canyon Dam

Although there are dozens of plans and regulatory processes (e.g., Federal, state, local, and private) to reduce sediment input in areas upstream of the HCC, the trapping efficiency of the HCC reservoirs and other water resource projects upstream is high, and therefore, sediment input from areas upstream of Hells Canyon Dam is considered negligible.

Snake River Downstream of Hells Canyon Dam

Practices

Under the Wild and Scenic River, National Recreation Area, and Wilderness designations, little or no development would be anticipated and sediment levels would likely remain at current or lower levels. For management of National Forest lands, the trend is to reduce sediment inputs to water bodies through updated standards and guidelines, Land and Resource Management Plans, and other regulatory mechanisms that specifically address sediment issues associated with timber harvest, road management (including construction measures and road decommissioning), and riparian habitat protection/management.

On private lands in the northern portion of this reach (on the Idaho side of the river), most of the land use in this area is agriculture (Figure 2). A large number of agencies, Tribes, and citizen groups are addressing sediment input problems, mainly in relation to loss of productive soil and potential impacts on aquatic habitat and fish species listed under the ESA. Examples include the Asotin County Conservation District, NRCS, WSU Cooperative Extension and others (Kuttle 2002). In addition, soil erosion issues are addressed under the Federal CWA, Farm Security and Rural Investment Act of 2002, Water Resources Development Act, and others.

BMPs have been published in the Idaho Agricultural Pollution Abatement Plan for agricultural practices (including grazing). However, these are largely voluntary at this time. Improvements are generally implemented with willing landowners through the efforts of several agencies (e.g., NRCS, soil and water conservation districts, Idaho Department of Fish and Game, Idaho Department of Water Resources, Nez Perce Tribe, and not-for-profit groups).

Examples of BMPs that are being implemented include no-till/direct seeding, installation of terraces, sediment basins, vegetated filter strips, and enrollment of acreage in the CRP. This voluntary program is directed at conversion of annual cropland to perennial grass stands for wildlife habitat benefits – which, in turn, stabilizes soils and reduces sediment input to streams.

Other measures include improving riparian buffers through approaches such as fencing to exclude livestock, planting degraded areas, and development of alternate livestock watering areas. Instream measures include placement of large rocks and large woody debris, which tend to restrict movement of sediments.

Funding for many of the habitat improvement projects is derived from the BPA. Under this funding, the organization that implements a particular project needs to follow BMPs developed by the BPA and other Federal, state, or local permitting requirements (BPA 1997). Additional funding sources can include the Salmon Recovery Funding Board in Washington

State, the OWEB in Oregon State, the EPA, and the Corps (e.g., projects under the Water Resource Development Act).

Projects

No specific projects to restore or reduce sediment were identified in IPC's license application. However, tentative plans for reducing sediment input via road management BMP has been proposed for the HCC relicensing for areas within the project boundary. In addition, IPC found that about 6 acres of shoreline have eroded along the Snake River below Hells Canyon Dam over the past 30 years. IPC attributes this to a number of potential causes including its operations and to other activities such as boat-driven waves, camping, trails, dispersed recreation, livestock grazing, and road or other construction or maintenance activities under the action of Federal agencies, public interest groups, or private landowners.

Outside of its own operations, IPC has indicated that it has little management authority to implement enhancement or restoration plans because most of these activities fall under the jurisdiction of the Forest Service, which manages the majority of the downstream lands along this reach. The lands managed by the Forest Service are primarily in the categories of wilderness, Wild and Scenic River, or National Recreation Area where minimal or no development would likely occur.

In areas downstream of the confluence with the Salmon River, a large number of projects have been implemented or are planned for private or public lands. These include projects funded for habitat restoration, BMPs for croplands, better road management, and other potential measures to decrease the current levels of sediment input to the Snake River. Most of these are tiered to programs directed at either restoration or enhancement of habitat for species listed under the ESA, soil conservation, or regulations promulgated under the Federal CWA.

Imnaha Subbasin

Practices

More than half of the Imnaha River basin is managed by the Forest Service (particularly in the eastern half of the upper basin) as multiple use forest lands or as wilderness. As such, these lands would be managed under a no development scenario (wilderness) or under Forest Service standards and guidelines, which are designed to maintain or improve existing conditions (e.g., decrease sediment input). Therefore, there is likely to be decreases in sediment input from these lands in the future.

Other portions of the Imnaha River basin are in private ownership. A wide variety of regulatory processes (e.g., TMDL, shoreline management, subbasin plans, and others) and voluntary programs (e.g., CREP) are designed to decrease sediment loading, particularly from croplands or grazing, on private lands. In addition, habitat restoration or protection measures have been implemented (mainly for salmon recovery in relation to the ESA) or will be implemented by various groups such as BPA, the Salmon Resource Recovery Board, the OWEB, and public or private groups. It is anticipated that this trend to stabilize habitat through these various groups, agencies, or Tribes will continue into the future, thus further decreasing sediment inputs.

Projects

The Subbasin Plan indicates that there are "currently, and have been historically, numerous enhancement/restoration efforts designed to improve instream habitat diversity throughout various portions of the Imnaha subbasin." It is likely that many of these would contribute to stream stability and thus, reduce sediment inputs. For example, livestock exclosures and woody debris reintroductions by the Forest Service have improved gravel accrual rates in the mainstem Imnaha River (Ecovista 2004a).

Specific strategies that are directly related or indirectly related to promoting decreased sediment inputs in the Imnaha River Basin are outlined in the Subbasin Plan. Already numerous habitat improvement projects have been constructed or management plans implemented. Future funding, however, is an unknown. Specific strategies include:

- Maintain currently functioning wetlands and restoration of degraded wetlands
- Maintain currently functioning riparian areas and restore degraded riparian areas
- Reduce the impact of the transportation system on wildlife and fish populations and habitats
- Restore the composition, structure, and density of forests to within the historic range of variability
- Restore non-functional riparian zones, maintain/protect functional riparian zones, ameliorate grazing impacts, restore natural floodplain processes, restore channel form
- In problem areas, reduce sedimentation impacts to aquatic focal species
- Reduce the risk of catastrophic fire

The Subbasin Plan also prioritizes many of these measures in specific areas throughout the Imnaha River Basin. In addition, specific areas in the Imnaha River basin have been designated in the Subbasin Plan for protection, protection and restoration, and restoration.

Asotin Subbasin

Practices

The Subbasin Plan identifies (in specific reaches of Asotin Creek), the causes of habitat deterioration, assumptions considered, hypotheses for testing, and assumptions. It also identifies priority protection area strategies.

In addition to these plans, the Asotin Creek Subbasin Plan also has established a management plan that is directed at enhancement of aquatic and terrestrial habitat over the next 10 to 15 years. The plan is to be implemented by landowners, conservation districts, agencies, tribes, and others. The plan is voluntary, and will be implemented, to the extent possible, by BPA funds or other available funding sources.

Projects

The Asotin Subbasin Plan indicates that multiple projects to improve or protect aquatic and terrestrial habitats have been implemented by Federal, state, tribal, and local entities. For example, the Plan indicates that, since 1996, a total of 581 fish habitat-related projects have been implemented (through May 2004). Most of these projects directly or indirectly affect sedimentation. They include various activities such as:

- Instream habitat construction
- Direct seeding
- Establishment of permanent grasses/pastures/haylands
- Sediment basin construction/maintenance
- Upland multi-purpose pond construction
- Terrace construction
- Reforestation/tree planting
- Spring development
- Erosion control (critical area planting, grassed waterways, conservation cover)
- Pipeline installation
- Water gaps and windbreaks
- Riparian fencing and tree planting

7.5 SUMMARY OF PRELIMINARY CONCLUSIONS

Upstream of Hells Canyon Dam

Inputs of sediment to the Snake River from areas upstream of Hells Canyon Dam are likely negligible, based on the studies by IPC, the number of major water resource facilities (primarily dams), and increasing regulatory requirements focused on decreasing sediment inputs. Therefore, it is recommended that no priority be initially assigned to this potential source of sediments and that no further considerations be made for evaluations of sediment inputs from upstream of HCC, unless current conditions (e.g., regulatory constraints, continued operation of the HCC and other water resource facilities) change significantly.

Snake River Downstream of Hells Canyon Dam

The Forest Service manages the majority of lands in the upstream half of this reach. Sediment input does occur from tributaries and estimates of the volumes of sediment have been made by IPC (2003). Other potential contributors are likely small (e.g., erosion of stream banks and sandbars, movement of bedload, and hillslope erosion) because this reach has been generally characterized as stable (due to regulated flows, arid climate, and minimal upslope activities on federally managed lands such as the Wild and Scenic River, National Recreation Area, and Wilderness Areas). Overall, unless a catastrophic hillslope failure or other similar unanticipated event occurs (e.g., major flood), the sediment input to the Snake River from sources in this reach is likely small. In addition, the future trend would be expected to remain at existing levels or somewhat lower due to upslope management practices (particularly by the Forest Service) that would tend to decrease inputs (e.g., through increase road management activities).

The IPC information concerning sediment input from the 17 tributaries appears to be of interest in considering the overall sediment sources and transport within the Snake River upstream of its confluence with the Clearwater River (IPC 2003). In addition, one of the tributaries (Divide Creek) involves land ownership that is primarily private. IPC's information on the 17 tributaries can be evaluated for its potential for incorporation into the overall study. Also, the TMDL for Tammany Creek should be useful for evaluating small local drainages in the lower portion of the Snake River reach between Hells Canyon Dam and the confluence with the Clearwater River.

For other areas on private lands, a number of funding mechanisms and habitat restoration/soil conservation/water quality programs are designed to improve stability within these watersheds, thus providing a reduction in sediment input.

Imnaha Subbasin

As indicated in the Subbasin Plan, the Imnaha River basin is in generally good condition compared to other subbasins in the Columbia River basin. Conditions have improved over historic levels as a result of increased emphasis (particularly on the National Forest System lands) on improving habitat (both terrestrial and aquatic), which provides a trend to increased stability and less sediment input to the system. However, catastrophic events such as the 1997 flood cannot be predicted, and thus, conditions could change.

Overall, with the generally good conditions in the Imnaha River subbasin and the specific strategies in place to further stabilize the subbasin, sediment inputs should decrease in the future. With a large portion of the subbasin managed as National Forest and with updated approaches for managing these lands to improve or protect aquatic resources (e.g., road decommissioning, protection of riparian areas, etc.), this should enhance the overall basin efforts.

With the subbasin planning process well underway, opportunities for the Corps might include participation on some projects that specifically address major sediment issues or possible joint funding for these types of projects.

Asotin Subbasin

Overall, the specific strategies in place to further stabilize the Asotin Creek Subbasin, sediment inputs should decrease in the future. The upper portion of the subbasin is managed as National Forest and with updated approaches for managing these lands to improve or protect aquatic resources (e.g., road decommissioning, protection of riparian areas, etc.). This should enhance the overall basin efforts. In addition, processes are in place to reduce sediment inputs from agricultural lands. However, the agricultural areas in the lower portion of this subbasin including adjacent areas along the Snake River, likely produce a considerable amount of sediment input to the Snake River.

With the subbasin planning process well underway, opportunities for the Corps might include participation on some projects that specifically address major sediment issues or possible joint funding for these types of projects.

8. GRANDE RONDE RIVER SUBBASIN

8.1 THE SETTING

8.1.1 Geography and Topography

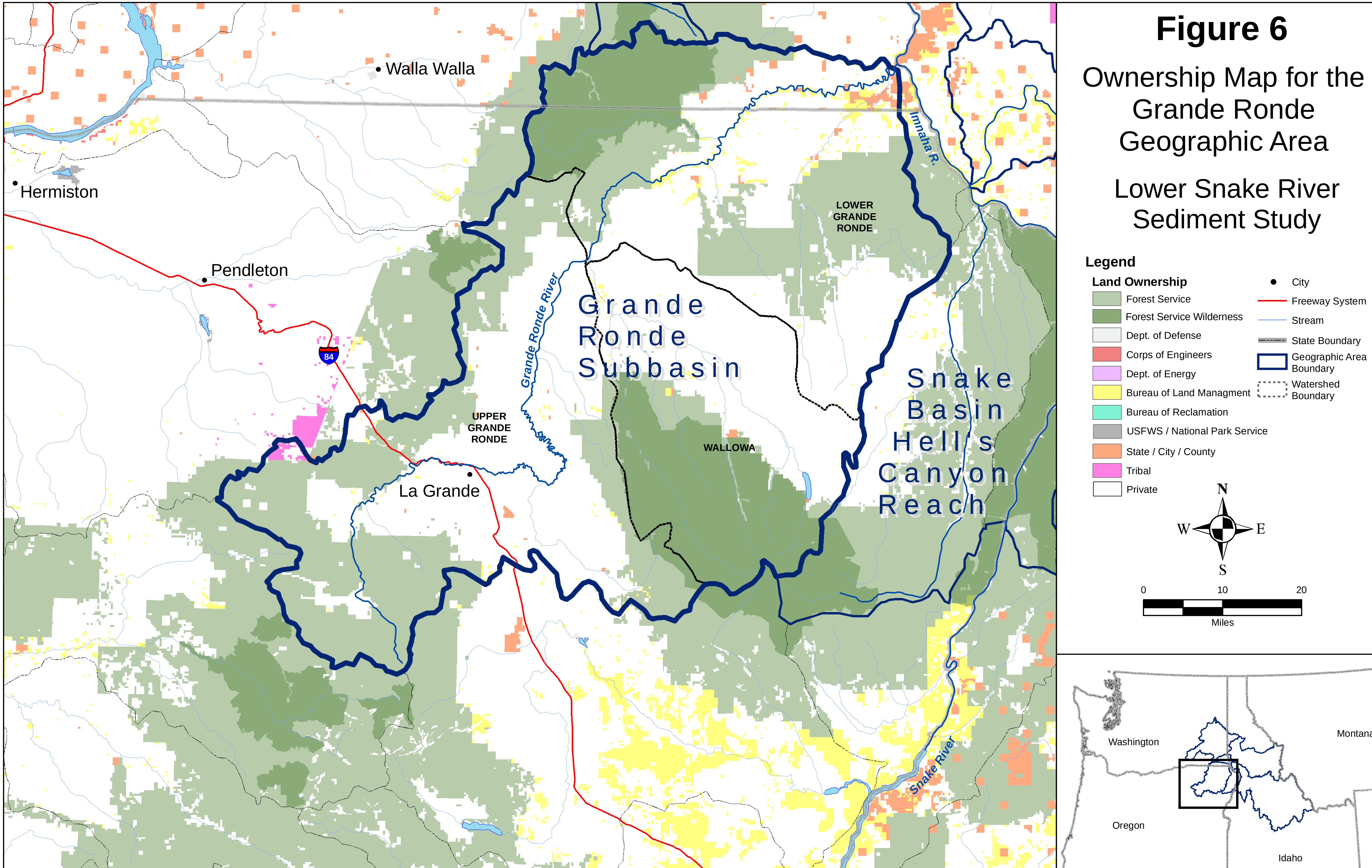
The Grande Ronde River subbasin comprises 4,130 square miles with the majority of the subbasin in northeastern Oregon and a small portion in southeastern Washington (Figure 6). It consists of three 4th-field (HUC) watersheds, the Upper Grande Ronde, Wallowa, and Lower Grande Ronde (Table 28.). The basin consists largely of rugged mountains and includes portions of the Blue Mountains in the west and northwest and the Wallowa Mountains in the southeast. Peaks in the Blue Mountains reach elevations of 7,700 feet and those in the Wallowas reach nearly 10,000 feet. The Grande Ronde and Wallowa Rivers flow through major valleys at relatively high elevations. The Grande Ronde valley is relatively flat valley at elevations between 2,600 and 2,800 feet and the Wallowa valley is steeper and lies at elevations between 2,800 and 4,700 feet. The Grande Ronde flows into the Snake River about 20 miles upstream of the town of Asotin, Washington (Grande Ronde Model Watershed Program 2004).

Table 28. Size and Cataloging Unit Number for Watersheds within the Grande Ronde River Basin

Watershed Name	Cataloging Unit Number	Area (Square Miles)	Percent of Study Area
Upper Grande Ronde	17060104	1,650	40%
Wallowa	17060105	950	23%
Lower Grande Ronde	17060106	1,530	37%
Total Grande Ronde River Basin		**4,130**	**100%**

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

The Grande Ronde subbasin has a complex geologic history. Rocks of the Columbia River Basalt Group dominate the surface geology of the area. Rocks older than the Columbia River Basalts occur only in the headwaters areas of the Grande Ronde River, the Wallowa River, and Catherine Creek. These rocks consist of granitic intrusives and older volcanics with associated sedimentary deposits. The structural geology of the area is also complex and many faults cut the bedrock formations. These faults follow a general northwest-southeast trend. The presence of hot springs and regional, deep ground water flow systems indicate ongoing tectonic activity (Grande Ronde Model Watershed Program 2004). Soils in the Grande Ronde River subbasin are highly variable and may range from those on thin, rocky, low-productivity ridgetop scablands to those in deep ash accumulations on very productive sites.



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8.1.2 Hydrology

The climate of the Grande Ronde River Basin is variable as a result of the high relief of the Blue and Wallowa Mountains. However, winters are generally cold and moist and summers are warm and dry. Average annual precipitation increases from 14 inches on the valley floor to over 60 inches in some mountain areas.

The major streams that flow into the Grande Ronde include Catherine and Joseph creeks and the Wallowa and Wenaha Rivers. Catherine Creek and the Wallowa River originate in the Eagle Cap Wilderness and the Wenaha River originates in the Wenaha-Tucannon Wilderness. The Grande Ronde and its tributaries are snowmelt runoff streams. Peak runoff occurs in spring, generally from April through June, from melting snowpack and spring rains, and low flows occur in late summer. The Wallowa River flows into Wallowa Lake, which is the only large lake in the study area. Although it is a natural lake, a dam was constructed at its outlet and its storage is used primarily for irrigation. The majority of its drainage basin is in the Eagle Cap Wilderness. There are also a number of small impoundments in the subbasin.

8.1.3 Land Cover

At one time grasslands, dominated much of the Grande Ronde subbasin. However, plowing, burning, irrigating, grazing, and mowing have converted many of these lands to agricultural cover types. Remnant strips of the native grassland steppe still exist within farming areas, but these are generally confined to areas inappropriate for farming (Grande Ronde Model Watershed Program 2004). Currently, grasslands cover about 12 percent of the subbasin overall, ranging from 21 percent in the Lower Grande Ronde to 4 percent in the Upper Grande Ronde watershed (Table 29). Agricultural and urban types occupy 17 percent of the subbasin, ranging from 22 percent in the Upper Grande Ronde to 11 percent in the Lower Grande Ronde watershed.

As elevation increases, scrub-shrub vegetation occurs and coniferous forests eventually dominate. Forest types cover about 70 percent of the entire subbasin. Diverse wetland communities also occur throughout the subbasin. Table 29 summarizes the extent of general land cover types within the subbasin, by 4th-field watershed.

Table 29. General Land Cover by Watershed within the Grande Ronde River Basin (percent of total watershed area)

Watershed Name	Agricultural and Urban	Herbland	Shrubland	Early-seral Forest	Mid-seral Forest/ Woodland	Late-seral Forest	Other[1/]
Upper Grande Ronde	22%	4%	<1%	16%	52%	6%	<1%
Wallowa	17%	14%	<1%	23%	24%	18%	3%
Lower Grande Ronde	11%	21%	<1%	25%	39%	4%	<1%
Total Grande Ronde Subbasin	**17%**	**12%**	**<1%**	**21%**	**41%**	**8%**	**1%**

[1/] Riparian, Alpine, Water, Rock, Barren
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

8.1.4 Land Ownership

The Forest Service is the largest single land manager in the Grande Ronde basin, managing 47 percent (Table 30). Wallowa-Whitman and the Umatilla National Forest lands make up a similar percentage of all three watersheds ranging from 46 to 49 percent. The BLM manages a small amount of land in the Lower Grande Ronde and scattered parcels in the other watersheds, totaling 1 percent of the subbasin overall. The states of Oregon and Washington also manage lands in the Lower Grande Ronde, and the state of Oregon also manages limited parcels in the other watersheds. State ownership within the subbasin also totals approximately 1 percent. Privately owned lands occur extensively at lower elevations along stream valleys and on the valley floors, especially along the Grande Ronde and Wallowa valleys and along portions of the Joseph Creek headwaters and within higher elevation meadows of the Upper Grande Ronde. Private ownerships comprise just over half of the entire subbasin and make up 47 to 53 percent of each watershed.

Table 30. Land Ownership by Watershed within the Grande Ronde River Basin (percent of total watershed area)

Watershed Name	Private	Tribal	State	National Forest (non-Wilderness)	National Forest Wilderness	BLM
Upper Grande Ronde	53%	<1%	<1%	45%	1%	<1%
Wallowa	53%	0%	<1%	4%	43%	<1%
Lower Grande Ronde	47%	0%	1%	33%	16%	2%
Total Grande Ronde Subbasin	**51%**	**<1%**	**1%**	**31%**	**16%**	**1%**

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

8.1.5 Land Use

Approximately 16 percent of subbasin lands are in designated wilderness. The Wallowa watershed, in particular, has 43 percent of its area in the Eagle Cap Wilderness. The Wenaha-Tucannon Wilderness makes up 16 percent of the Lower Grande Ronde and both wildernesses combine to make up 1 percent of the Upper Grande Ronde. The remaining National Forest System lands are managed for multiple uses, especially timber production, livestock grazing, and recreation. Although the Grande Ronde Subbasin contains extensive private lands, it is sparsely populated. Primary uses of private land are for cropland, range management, and timber management. Major crops include wheat, hay and forage, grass and legume seeds, peppermint, potatoes, and specialty crops.

Road densities are moderate to high throughout the majority of the subbasin (63 percent); however, they are absent to very low in the wilderness and adjacent areas (22 percent) (Table 31). Lowest overall densities are in the Wallowa watershed and the highest are in the Upper Grande Ronde.

Table 31. Road Density Predicted Classes by Watershed within the Grande Ronde Subbasin (percent of total watershed area).

Watershed Name	Road Miles per Square Mile					
	0 – 0.02	**0.02-0.1**	**0.1-0.7**	**0.7-1.7**	**1.7-4.7**	**>4.7**
Upper Grande Ronde	3%	1%	13%	24%	45%	13%
Wallowa	43%	<1%	2%	31%	21%	2%
Lower Grande Ronde	23%	3%	6%	27%	35%	6%
Total Subbasin	**20%**	**2%**	**8%**	**27%**	**36%**	**8%**

Source: Map 3.28, Volume II, in Quigley and Arbelbide (1997). Data used to form these classes was statistically extrapolated from sampled 6th-field HUC road data.

8.2 OVERVIEW OF SEDIMENT TRENDS AND HISTORIC CHANGE

Historic changes in the Grande Ronde Subbasin that affect sediment are primarily related to road construction, agriculture, timber harvest, and grazing. Extensive roading has been conducted along streams in the subbasin. Overgrazing of riparian zones, conversion of grasslands to agricultural uses, water diversions, and timber harvest have occurred in many areas. Gold dredging has occurred in the upper Grande Ronde above Starkey (McIntosh et al. 1994). All of these changes have contributed to sediment production and transport to streams.

Table 32 presents some ratings developed by Interior Columbia Basin Ecosystem Management Project (Quigley and Arbelbide 1997), which can be used as overall indices of the relative level of disturbance in each watershed within the geographic area. The measures relate to the degree of hydrologic disturbance in forest and rangeland environments (based on the level of surface mining, dams, cropland conversion, and roads) and the degree of riparian disturbance in rangeland environments (based on the sensitivity of streambanks to grazing and the sensitivity of stream channel function to the maintenance of riparian vegetation).

Based on these ratings, some broad generalizations can be made. The overall level of disturbance is high in the Upper Grande Ronde watershed for all categories. For the Wallowa and Lower Grande Ronde, the level of hydrologic disturbance in forest environments is high, but the levels of hydrologic and riparian disturbance in rangeland environments are moderate.

Table 32. Hydrologic Disturbance Rating of Forest and Rangeland Environments and Riparian Disturbance Rating of Rangeland Environments Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Grande Ronde Geographic Area

Watershed Name	Hydrologic Disturbance Rating of Forest Environments	Hydrologic Disturbance Rating of Rangeland Environments	Riparian Disturbance Rating of Rangeland Environments
Upper Grande Ronde	High	High	High
Wallowa	High	Moderate	Moderate
Lower Grande Ronde	High	Moderate	Moderate

Source: Maps 2.34, 2.35, and 2.36, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

8.3 SEDIMENT SOURCES AND YIELD

8.3.1 Overview Studies of Erosion and Mass Wasting Hazards

In this section, ratings and other results from a number of overview studies that were conducted across the entire Columbia River basin or over larger areas are presented for perspective and comparison purposes. The methods behind these studies are summarized briefly below and in more detail in Section 4.1.

The Interior Columbia Basin Ecosystem Management Project conducted by the Forest Service and the BLM (Quigley and Arbelbide 1997) developed various soil erosion, mass failure, and sediment hazard ratings for nonpoint sources for each watershed, relative to all Columbia Basin watersheds. The key ratings are shown for the Grande Ronde Subbasin, in Tables 33 and 34.

Table 33. Soil Erosion, Mass Failure, and Sedimentation Measures Relative to the Entire Columbia Basin by Watershed (Cataloging Unit) within the Grande Ronde River Basin

Watershed Name	Surface Soil Erosion Hazard	Earth Flow Hazard	Debris Avalanche Hazard	Sediment Delivery Potential	Sediment Delivery Hazard
Upper Grande Ronde	High	Mod - High	High	Mod - High	High
Wallowa	High	High	High	Mod - High	High
Lower Grande Ronde	High	High	High	Mod - High	High

Source: Maps 2.10, 2.11, 2.12, 2.13, and 2.15, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

Table 34. Road Erosion Hazard and Road Sediment Delivery Hazard Relative to the Entire Columbia Basin by Watershed (Cataloging Unit) within the Grande Ronde River Basin

Watershed Name	Road Erosion Hazard	Road Sediment Delivery Hazard
Upper Grande Ronde	Low to Moderate	Moderate to High
Wallowa	Moderate to High	High
Lower Grande Ronde	Low	Moderate to High

Source: Maps 2.16 and 2.17, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

NMFS (Baker et al. 2005) has developed two draft models for estimating increases in erosion rates relative to natural levels. Based on this study, erosion rates in the Upper Grande Ronde watershed are 1 to 4 times historical rates, 1 to 5 times in the Wallowa watershed, and 1 to 6 times in the Lower Grande Ronde.

The USGS developed a landslide overview map (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas which are susceptible to landsliding in the conterminous United States. Within the geographic area, there is an area along the Washington-Oregon border within the Lower Grande Ronde watershed (primarily in the Wenaha drainage) that is mapped as having a high incidence of past landslides and susceptibility to future landslides. This area is largely on National Forest System lands and mostly in the Wenaha-Tucannon Wilderness. In addition, there is another area along the boundary of the Upper and Lower Grande Ronde watersheds that is mapped similarly.

A NRCS analysis of cropland for 1997 in the conterminous United States found that the subbasin had some areas of highly erodible cropland with excessive erosion above the tolerable soil erosion rate (NRCS 2000). These areas were primarily in the Upper Grande Ronde and Wallowa watersheds.

8.3.2 Specific Studies within the Geographic Area

The ODEQ has identified many streams in the Grande Ronde Subbasin as water quality limited (or 303(d) listed) for at least one of a number of water quality parameters of concern. Sedimentation is one of the most widespread parameters and 20 stream segments in the Upper Grande Ronde, 2 in the Lower Grande Ronde, and 4 in the Wallowa watershed are 303(d) listed due to sedimentation.

A TMDL and Water Quality Management Plan (WQMP) and Agricultural Water Quality Management Area Plan (AWQMAP) have been developed for the Upper Grande Ronde River watershed (ODEQ 2000) and are in development for the lower Grande Ronde (in Oregon) and Wallowa watersheds. The WQMP prioritized 11 geographic areas within the

Upper Grande Ronde watershed for treatment (Grande Ronde Water Quality Committee 2000). The priorities assigned for treatment of sediment are presented in Table 35.

Table 35. Geographic Priority Areas for Treatment of Sediment in the Upper Grande Ronde Watershed

Watershed	Priority
Lookingglass	Low
Lower Grande Ronde	Low
Willow/Philips	High
Indian/Clark	Medium[1/]
Catherine Creek	High
Beaver	Medium
GRR Valley	High
Ladd Creek	High
Upper Grande Ronde	High
Meadow Creek	High
Spring/Five Pts.	Medium

[1/]Clark Creek probably should be "high" for sediment but the watershed as a whole is medium.
Source: Grande Ronde Water Quality Committee 2000

The WQMP noted that the three parameters commonly listed throughout the subbasin (i.e., sediment, habitat modification, and temperature) can all be improved through management decisions that would lead to improving vegetation conditions. Thus, practices that improve vegetative conditions are high priorities for improving water quality in the subbasin. In general, solutions that involve stabilizing slopes and stream banks, narrowing and deepening channels (decreasing width to depth ratio), and increasing shade by restoring woody vegetation in areas where it has been removed (primarily in riparian areas) will lead to improvement in habitat, sediment loss and temperature. Reducing sediment from roads, or intercepting it before it reaches a stream, is also an approach with large potential benefits (Grande Ronde Water Quality Committee 2000).

Many assessment studies have been conducted in the Upper Grande Ronde Subbasin (Bach 1995; Clearwater BioStudies 1993; Diebel 1997; Hemstrom et al. 2002; Mobrand Biometrics 1997; ODEQ 1997; NRCS/USDA Forest Service/Union County Soil and Water Conservation District 1997; USDA Forest Service 1999; BLM 1993;). Detailed discussions of the abundant water quality monitoring data available in the subbasin can be found in the following two documents: Grande Ronde River Basin Water Quality Technical Assessment – Temperature (ODEQ, May 1998) and Grande Ronde River Basin Water Quality Technical Assessment (Overview of Water Quality Conditions) (ODEQ, May 1998).

8.4 MANAGEMENT PRACTICES AND RESTORATION

Sediment management within the Grande Ronde Subbasin is tied to a mixture of plans, policies, and regulations and depends on the landowner. Areas with the highest protection status and which have a management plan that maintains a natural state are the two wildernesses managed by the Forest Service – the Eagle Cap, which is mostly in the Wallowa watershed and the Wenaha-Tucannon, which is mostly in the Lower Grande Ronde watershed. The Eagle Cap and Wenaha-Tucannon are 361,000 acres and 177,000 acres in size, respectively, including some lands outside the subbasin. Combined, these two wildernesses represent 16 percent of the subbasin (Table 30).

A moderately high protection status is also afforded a number of riverine corridors that are designated as Federal Wild and Scenic Rivers and are managed by the Forest Service within the National Forests of the subbasin and by the BLM outside the Forests. These include the Oregon portion of the lower Grande Ronde River and portions of Joseph Creek and the Wenaha River in the Lower Grande Ronde watershed, and portions of the Lostine and Minam Rivers in the Wallowa watershed.

The Forest Service is the single largest land manager in the subbasin, managing 47 percent of the subbasin (including wilderness). The Wallowa-Whitman and Umatilla National Forest Plans were approved in 1990 and are under revision.

The BLM manages only 1 percent of the subbasin. A Resource Management Plan for the BLM's Baker Resource Area was approved in 1989; a revision is scheduled to begin in 2006.

The Forest Service Forest Plans and BLM Resource Management Plan in the subbasin were amended in the mid-1990s to provide additional protection of riparian areas and improve water quality because of PACFISH and INFISH. PACFISH and INFISH will provide management direction on Federal lands until Forest Plans and Resource Management Plans are revised within the next several years.

Other lands with a relatively high degree of protection status include nearly 20,000 acres of wildlife areas managed by the Washington and Oregon Departments of Fish and Wildlife and 15,000 acres of land called the Precious Lands area of the Nez Perce Tribe. These lands are mostly within the Lower Grande Ronde watershed.

The Grande Ronde Model Watershed Program was designated in 1992 by the NPPC to be the model watershed for Oregon to coordinate restoration work in the Grande Ronde Subbasin. The Program was entrusted by the BPA to oversee the planning and implementation of new projects using BPA funds. Grande Ronde Model Watershed Program oversight has provided consistency in project implementation in the Grande Ronde Subbasin.

On private agricultural lands, the USDA's Farm Service Agency and NRCS administer many farm programs which have been used extensively in the subbasin to reduce agricultural impacts to riparian areas and water quality. The CRP, which puts sensitive croplands under permanent vegetative cover, the CREP, which helps establish forested riparian buffers, and the WRP, which helps protect and enhance privately owned wetlands, are three of the most used programs.

The Oregon Department of Forestry enforces the Oregon Forest Practices Act regulating commercial timber production and harvest on state and private lands in Oregon. The Oregon Forest Practices contains guidelines to protect fish-bearing streams during logging and other forest management activities, which address stream buffers, riparian management, and road maintenance. Similarly, the Washington Department of Natural Resources (WDNR) enforces the Washington Forest Practices Act, which guides and restricts logging and other forest management activities on state and private lands in Washington. Although these regulations are more restrictive than Oregon's, they only affect limited lands in the Lower Grande Ronde watershed.

Over 400 on-the-ground restoration projects were accomplished in the Grande Ronde Subbasin in the last decade (Grande Ronde Model Watershed Program 2004). Many of these were implemented through the Grande Ronde Model Watershed Program using BPA fish and wildlife mitigation funds. Others were done by agencies without the assistance of BPA. These projects are identified in Grande Ronde Model Watershed Program (2004).

Based on the results of the EDT model (Mobrand Biometrics 2006), the Grande Ronde Model Watershed Program (2004) summarized the additional opportunities for fish habitat restoration by watershed, within the entire Grande Ronde Subbasin. The following items identify some of the important observations they made relative to sediment.

Lower Grande Ronde Watershed (4th-field HUC) (Grande Ronde Model Watershed Program 2004)

- Wenaha – this watershed is almost entirely within the Wenaha-Tucannon Wilderness and has had few impacts and it is likely that conditions will remain stable
- Lower Grande Ronde
- Lower Grande Ronde Tributaries 1 geographic area – mostly private lands, almost all tributaries have roads along the streams, and the area has been identified as having sediment impacts in almost all tributaries and as a priority for restoration
- Wildcat Creek geographic area – sediment inputs from grazing and roads are key factors

- Courtney Creek geographic area – minimizing sediment impacts from roads and grazing should be priority actions in this area
- Mud Creek geographic area – minimizing sediment impacts from roads and grazing should be priority actions in this area
- Lower Grande Ronde Tributaries 2 geographic area – some sediment impacts
- Grossman Creek geographic area – minimizing sediment impacts from roads and grazing should be priority actions in this area
- Joseph Creek – overall, this is one of the most heavily roaded watersheds in the Grande Ronde Subbasin; private ranching and grazing are the dominant land uses and many observed impacts can be tied to these activities
- Lower Chesnimius geographic area – mostly private lands with extensive areas of grazing and ranching
- Lower Joseph – sediment impacts in this area are likely from activities upstream
- Upper Joseph – reaches are relatively low gradient, passing through a mix of National Forest System lands and private lands; there are some large ranches with extensive grazing
- Swamp Creek – mix of National Forest System and private lands with extensive grazing
- Crow Creek geographic area – significant sediment impacts have been observed in Crow Creek; this is one of the best areas for restoration
- Upper Chesnimius geographic area – this is one of the most heavily roaded portions of the Grande Ronde Subbasin
- Cottonwood Creek – lands managed by Forest Service, BLM, and private owners
- Joseph Creek Tributaries geographic area – almost entirely on National Forest System lands
- Main Grande Ronde geographic area – river is in relatively confined canyon with a parallel road

Wallowa Watershed (4th-field HUC) (Grande Ronde Model Watershed Program 2004)

- Wallowa River
- Lower Wallowa River – sediment impacts are likely the result of upstream activities

- Lower Wallowa Tributaries – identifying and minimizing sediment inputs from stream adjacent roads should be a priority action
- Mid Wallowa River – a road and railroad parallel most of the reach
- Deer and Sage Creeks – roads parallel the entire lengths
- Mid Wallowa Tributaries geographic area – Water Canyon has a road the entire length and minimizing sediment should be a priority action
- Rock Creek geographic area – maintain and enhance riparian conditions to decrease sediment impacts
- Lower and Upper Bear Creek geographic areas – private lands, irrigation diversions, upper reaches are in wilderness
- Lower Whiskey Creek – farming, grazing, upper portion flows through private timber and grazing lands with a high density of roads
- Lower Lostine geographic area – irrigated agriculture, grazing, residential, and water diversions
- Upper Lostine geographic area – a road follows most of the stream
- Upper Wallowa River – towns of Enterprise and Joseph and many irrigation diversions
- Wallowa Lake Dam and Upper Alder Slope Diversions – significant barriers
- Spring Creek and Upper Wallowa Tributaries – roads and grazing, but area is a low priority for restoration or protection
- Lower and Upper Hurricane Creeks – rural residential, irrigation diversions, farming, and wilderness in the upper reaches
- Prairie Creek geographic area – Prairie Creek has a high sediment load, water is transferred to the creek from ditches
- Wallowa Lake – major impoundment
- Minam River – upper reaches are entirely within the Eagle Cap Wilderness, only the lowest portion is in private ownership, where roads follow the creek bottoms

Upper Grande Ronde Watershed (4th-field HUC) (Grande Ronde Model Watershed Program 2004)

- Lookingglass Creek – one of the most pristine non-wilderness watersheds in the Grande Ronde River basin, but much of the Lower Lookingglass is private timber

- Catherine Creek/Middle Grande Ronde
- Middle Grande Ronde and Tributaries, Phillips and Indian Creeks – ranching, grazing, and roads
- Willow Creek – ranching and farming
- Catherine Creek – EDT rated the middle Catherine Creek area as an overwhelming priority for restoration
- Ladd Creek – extensively modified wetlands for agriculture and roading
- SF and NF Catherine Creek areas – Forest Service road up the South Fork, North Fork Buck Creek, and other roads in the drainage; some tributaries are unroaded
- Upper Grande Ronde – many reaches rated as a priority, but none rated as a high priority; portions of the upper Grande Ronde River above Starkey have been impacted by gold dredging

In their Management Plan for the subbasin, the Grande Ronde Model Watershed Program (2004) identified the following list of strategies for controlling sediment in the watershed:

- Identify sediment sources
- Close, obliterate or relocate sediment-producing roads
- Improve drainage, install culverts, surface, on open sediment producing roads
- Manage grazing in riparian areas following grazing plans designed to improve riparian condition; could include exclusion, partial season use, development of off-site water, herding
- Reestablish riparian vegetation by planting trees, shrubs, sedges (native species preferred)
- Stabilize active erosion sites, where appropriate, through integrated use of wood structures (limited use of rock if necessary) and vegetation reestablishment
- Where appropriate and feasible, relocate channelized stream reaches to historic locations
- Promote interaction of stream channels and floodplains by removing, where feasible and appropriate) channel confinement structures (roads, dikes)
- Encourage landowner participation in riparian management incentive programs (e.g., CREP, WRP, EQIP)
- Promote/implement minimum tillage practices

- Promote/implement development of grazing plans to improve upland vegetative condition
- Implement an integrated noxious weed management program including survey, prevention practices, education, treatment and revegetation
- Create/construct wetlands and filter strips for livestock feedlots and irrigation return flows

8.5 SUMMARY OF PRELIMINARY CONCLUSIONS

In general, primary opportunities for sediment-related restoration efforts appear to be in the Upper Grande Ronde watershed. However, opportunities exist in the lower reaches of the Wallowa watershed and in some locations in the Lower Grande Ronde (e.g., Upper Chesnimius and Crow Creek drainages). Primary methods may include road obliteration or other road management measures for sediment producing roads, fencing or restoration of riparian vegetation where sediment production has been identified as a problem, relocation of channelized stream reaches, creation of wetlands or filter strips for drainage from agricultural areas, and other measures.

9. LOWER SNAKE RIVER BASIN – MOUTH TO LOWER GRANITE RESERVOIR

9.1 THE SETTING

9.1.1 Geography and Topography

The Lower Snake River Basin geographic area is located in the southeast corner of Washington and includes areas in western Idaho (Figure 7). It is defined as the area downstream of the mouth of the Clearwater River to its confluence with the Columbia River and includes four 4th-field watersheds (Table 36.). North of the Snake River is the Palouse and Rock Creek watersheds. South of the Snake River is the Tucannon watershed, which includes Alpowa Creek upstream of Lower Granite Dam, and the Tucannon River, Deadman, Panawawa, and Alkali Flat Creeks downstream of Lower Granite Dam. The fourth watershed is the Lower Snake, which lies downstream of the confluence with the Palouse.

Table 36. Size and Cataloging Unit Number for Watersheds within the Lower Snake River Subbasin

Watershed Name	Cataloging Unit Number	Area (Square Miles)	Percent of Study Area
Palouse	17060108	2,350	43%
Rock	17060109	957	17%
Subtotal Palouse and Rock		**3,308**	**38%**
Tucannon	17060107	1,463	27%
Lower Snake	17060110	700	13%
Total Subbasin		**8,779**	**100%**

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

Rock Creek flows into the Palouse River, which flows to the Snake River. Due to the size of Rock Creek watershed, it has been recognized with a separate Cataloging Unit Number. However, it is a peninsula of land in the northern portion of the Palouse watershed and it has basically the same setting and issues. Therefore, it is included in this discussion as part of the Palouse. The Palouse River originates in the Palouse Mountain Range in western Idaho, flows west through the rolling farm land where it is joined by Rock Creek and then south to the Snake River at the Whitman-Franklin County line downstream of the Little Goose Dam.

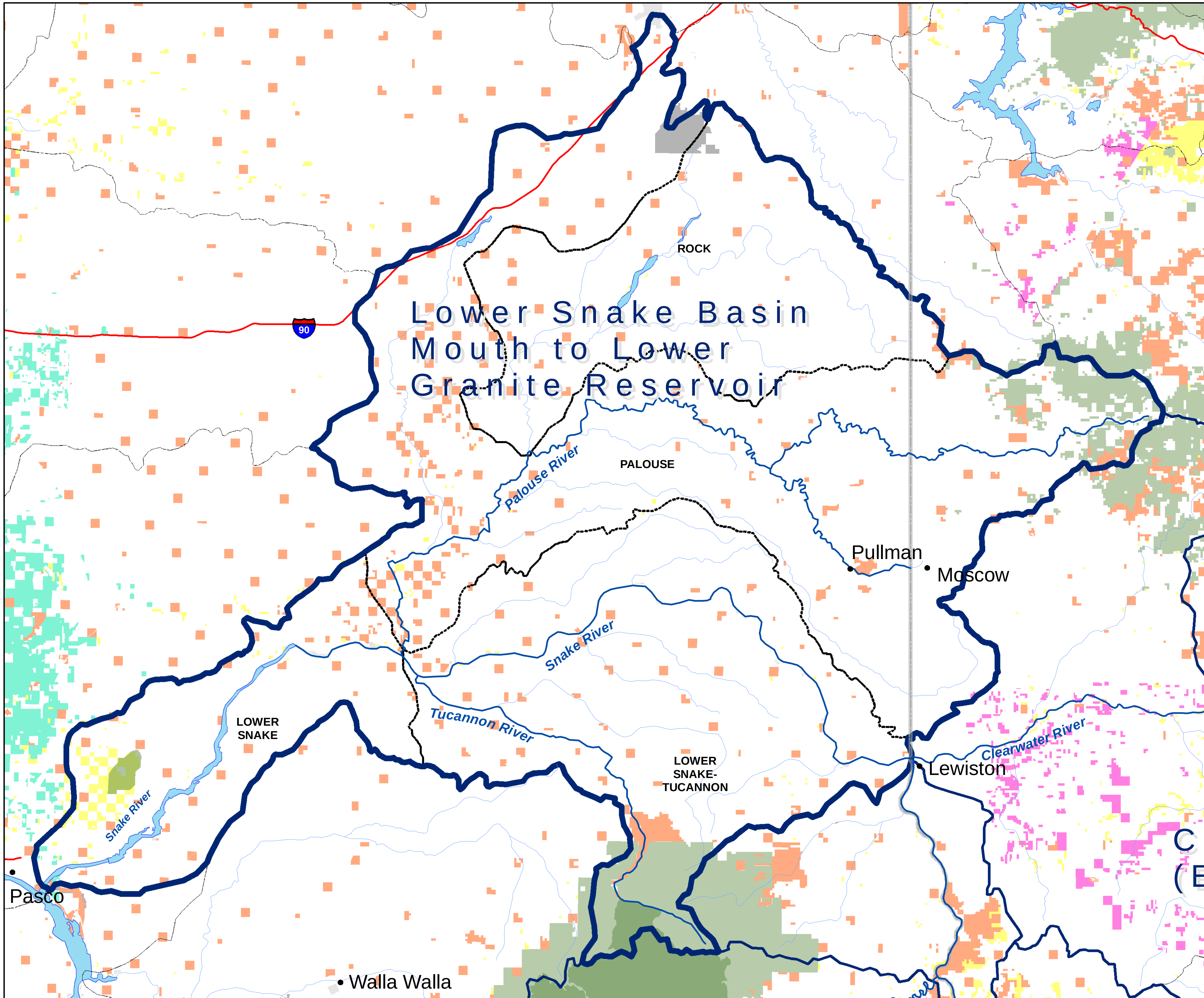

Figure 7

Ownership Map for the Lower Snake Basin - Mouth to Lower Granite Reservoir Geographic Area

Lower Snake River Sediment Study

Legend

Land Ownership

- Forest Service
- Forest Service Wilderness
- Dept. of Defense
- Corps of Engineers
- Dept. of Energy
- Bureau of Land Managment
- Bureau of Reclamation
- USFWS / National Park Service
- State / City / County
- Tribal
- Private

- City
- Freeway System
- Stream
- State Boundary
- Geographic Area Boundary
- Watershed Boundary

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Approximately 88 percent of the watershed is in eastern Washington and the remaining 12 percent is in western Idaho.

The rest of the Lower Snake River geographic area is within Washington. The Tucannon River, Deadman, and Alpowa Creeks originate in the Blue Mountains to the south. Alpowa Creek flows east and the others flow north and west to the Snake River. Other smaller tributaries to the Snake, Alkali Flat and Penawawa Creeks, originate north of the Snake in the hills between the Snake and Palouse Rivers, and flow east and south to the Snake.

Much of the Lower Snake River geographic area, north of the Blue Mountains and east of the Palouse Mountains, is characterized by dune-like ridges, deep wind-blown loess soils, and low gradient, often intermittent streams. Generally, the hills have gently sloping south and west facing slopes with short, steep north and east slopes and relief averaging 100 to 200 feet. The western portion of the basin in the Palouse region is in the channeled scablands where most of the loess that blanketed the basalt has been scoured away by a series of floods originating from Glacial Lake Missoula. The land surface in the scablands is characterized by "scabs" of basalt bedrock, loess islands, and sand and gravel flood deposits. Relief in the scablands, like the Palouse hills, averages 100 to 200 feet (Gilmore 2004).

There are two areas with different physical description. The eastern Palouse is in forested mountains of Idaho where elevation ranges to 5,330 feet and relief can be over 1,000 feet and the valleys are filled with alluvial deposits (Gilmore 2004). The southern Tucannon, in the Blue Mountains where elevations range to 6,400 feet, is characterized by long slopes intersected by steep canyons. The Tucannon watershed includes a major fault system, Hite Fault, which has been the locus of many historic earthquakes, is still active, and thought to be the cause of elevated ground water temperatures. It is approximately 85 miles in length and crosses both the Tucannon River and Pataha Creek at right angles (Columbia Conservation District 2004).

9.1.2 Hydrology

The climate is semi-arid with average annual precipitation ranging from as low as 5 inches in the western part of the Lower Snake River subbasin up to about 50 inches in the Palouse Mountains to the east and 40 inches in the Blue Mountains to the south. Snow normally comprises 60 to 70 percent of the total annual precipitation in the mountainous areas. Precipitation is mostly concentrated in the winter months (Kuttle 2002, Gilmore 2004).

There are five major tributaries to the Palouse River: the South Fork Palouse River, the North Fork Palouse River, Union Flat Creek, Rock Creek, and Cow Creek. There are many other intermittent or ephemeral streams and more than 40 lakes in the watershed. Many of the lakes are large water filled depressions with basalt bottoms and no outlet. Flows in the Palouse River and its tributaries vary seasonally, with high flows generally in early spring and low flows in late summer. The Palouse River and its tributaries have no major man-made impoundments. The Palouse River plunges over the 182-foot Palouse Falls approximately six miles up from its confluence with the Snake River. The falls act as a natural barrier for salmon and other migrating fish (Gilmore 2004).

The Tucannon Watershed is dominated by the Tucannon River. The river has two major drainages: the Pataha (36 percent of the watershed) and the mainstem Tucannon. Precipitation and ground water are the water sources for the Tucannon River and associated tributaries. Virtually all of the base flow in the Tucannon watershed comes from ground water discharge. Low flows are during late summer and peak flows are May/June when severe runoff events can lead to sediment problems in Pataha Creek and lower Tucannon River (Columbia Conservation District 2004). Average late summer flows are about 29 percent of the average spring flows [Water Resource Inventory Area (WRIA) 35]. The reservoir created by the Lower Monumental Dam, which is 20 miles downstream on the Snake River, has resulted in the lower two miles of the Tucannon River becoming a marshland (Middle Snake Watershed Planning Unit 2005).

The mainstem Snake River flows in a generally westerly direction to its confluence with the Columbia River. In addition to the Palouse and Tucannon Rivers, there are a number of smaller tributaries: the Alpowa, Deadman, and Meadow Creeks south of the river and Alkali Flat Creek, Penawawa Creek, Almota Creek, Wawawai Creek and Steptoe Canyon Creek north of the river. There are also a number of gulches (New York, Dry, and Fields gulches) or canyons (e.g., Walker Canyon). The Corps operates four major dams on the Snake River in this reach that provide power generation, water for irrigation, navigation, and recreation.

9.1.3 Land Cover

The Palouse region was historically covered with forest in the eastern mountains, grassland with scattered shrubs in the central area of rolling hills, and shrub-steppe and grassland in the eastern third (Kaiser 1975, Gilmore 2004). It is now highly altered with approximately 81 percent of the land being farmed for grain crops or developed. The Palouse grasslands are considered one of the most endangered ecosystems in the United States with less than one percent estimated to remain in a natural state. They cover less than two percent of the Palouse/Rock watersheds (Gilmore 2004).

Cultivated fields also dominate the Tucannon watershed with confer forest only in the Blue Mountains in the south. Areas of grassland and shrubland are concentrated along the larger streams. The Lower Snake Watershed is also predominantly agriculture but includes larger areas that remain shrub-steppe with some ponderosa pine and small wetland areas (Pomeroy Conservation District 2004). Table 37 summarizes the extent of general land cover types within the river basin, by 4th-field watershed.

Table 37. General Land Cover Percent by Watershed (4th-field HUC) within the Lower Snake River Basin Geographic Area (percent of total watershed area)

Watershed Name	Agricultural and Urban	Herbland	Shrubland	Early-seral Forest	Mid-seral Forest/ Woodland	Late-seral Forest	Other[1/]
Palouse	79%	4%	6%	<1%	11%	-	<1%
Rock	87%	1%	10%	<1%	2%	-	<1%
Subtotal Palouse and Rock	81%	3%	7%	<1%	8%	-	<1%
Tucannon	81%	4%	2%	2%	8%	<1%	1%
Lower Snake	65%	4%	26%	<1%	2%	-	2%
Total Subbasin	**79%**	**4%**	**8%**	**<1%**	**7%**	**<1%**	**<1%**

1\ Riparian, Alpine, Water, Rock, Barren

Source: Interior Columbia Basin Ecosystem Management Project GIS layers

9.1.4 Land Ownership

Private land ownership dominates the Lower Snake River subbasin, accounting for 92 percent of the land (Table 38). There are two large areas of concentrated National Forest System lands: approximately 48,200 acres in the Palouse Mountains managed by the Clearwater National Forest and 77,800 acres in the southern Tucannon managed by the Umatilla National Forest (of which 18 percent is wilderness). The only other large government-owned tract of land is 18,300 acres of BLM land in the Lower Snake, of which approximately a third is Juniper Dunes Wilderness. The Washington Department of Fish and Wildlife (WDFW) manages Wooten Wildlife Area, approximately 12,000 acres adjacent to the Umatilla National Forest and along the Tucannon River. While the Wooten Wildlife Area is protected to some extent, a salvage logging operation is currently underway after the 2005 School Wildfire (WDFW 2006). Three tribes have areas of interest within the Lower Snake River subbasin area: Nez Perce Tribe, Coeur d’Alene Tribe, and Spokane Tribe.

Table 38. Land Ownership by Watershed (Cataloging Unit) within the Lower Snake River Basin Geographic Area (percent of total watershed area)

Watershed Name	Private	State / County/ City	National Forest (non-Wilderness)	BLM (non-Wilderness)	National Forest and BLM Wilderness	U.S.FWS, DOD, or BOR
Palouse	92%	4%	3%	<1%	-	<1%
Rock	98%	2%	<1%	-	-	<1%
Tucannon	88%	3%	7%	-	2% 1\	-
Lower Snake	92%	3%	-	3%	1% 2\	<1%
Total Subbasin1	**92%**	**3%**	**3%**	**<1%**	**<1%**	**<1%**

1\ Wenaha-Tucannon Wilderness, Forest Service managed
2\ Juniper Dunes Wilderness, BLM managed
Source: Interior Columbia Basin Ecosystem Management Project GIS layers

9.1.5 Land Use

Approximately 64 percent of the land in the Palouse and Rock watersheds is used for dryland agriculture (wheat, barley, lentils and peas), dominating the central loess covered rolling hills. An additional 25 percent of the Palouse and Rock watersheds are used for livestock grazing, largely in the channeled scablands in the western portion of the watershed. It is estimated that today, fewer than a third of the farms have livestock. It is common for a producer to graze the animals on bottomlands during the spring, summer and fall months and then move the animals to a winter-feeding operation. An estimated 14 percent of the riparian areas within the watershed are grazed (Gilmore 2004). Timber activities are primarily concentrated in the eastern portion of the watershed. The major urban areas are Pullman, Washington, and Moscow, Idaho, where WSU and the University of Idaho are located, respectively.

In the Tucannon watershed, crops, forest, rangeland, and pasture comprise over 90 percent of the watershed with the remainder being protected (wilderness or managed by WDFW). Most of the non-forested land with slopes of 45 percent or less is under cultivation. The private land is primarily used for grazing and dryland agriculture (36 and 34 percent of the watershed respectively). Of the National Forest land in the watershed, only approximately one-quarter of the acres outside wilderness are considered suitable for harvest (Kuttle 2002).

Overall, road densities are low to moderate in this basin (Table 39). Road densities are high in the northern and eastern most portion of the Palouse watershed, areas with historical timber activities including unsurfaced roads that are more susceptible to erosion. In the areas with wind-blown loess soils, road building has also contributed to sedimentation by concentrating run-off and conveying it through road culverts where it can cut a gully across agriculture fields (Gilmore 2004).

Table 39. Road Density Predicted Classes by Watershed (4th-field HUC) within the Lower Snake River Basin Geographic Area (percent of total watershed area)

Watershed Name	Road Miles per Square Mile					
	0 – 0.02	**0.02-0.1**	**0.1-0.7**	**0.7-1.7**	**1.7-4.7**	**>4.7**
Palouse	1%	2%	74%	15%	6%	1%
Rock	<1%	1%	84%	12%	2%	<1%
Tucannon	4%	2%	61%	26%	6%	2%
Lower Snake	6%	3%	64%	24%	1%	2%
Total Subbasin[1\]	**2%**	**2%**	**71%**	**19%**	**5%**	**1%**

Source: Map 3.28, Volume II, in Quigley and Arbelbide (1997). Data used to form these classes was statistically extrapolated from sampled 6th-field HUC road data.

9.2 OVERVIEW OF SEDIMENT TRENDS AND HISTORIC CHANGE

The first inhabitants of this area were Native Americans. They utilized this area for grazing horses in the river bottoms and high meadows. Early activities by European settlers included trapping followed by farming. Dryland production of wheat expanded significantly in the 1870s (Kuttle 2002). Nearly all productive land was settled from 1870 through 1885 with completion of railroad vastly improving the marketing of agricultural products. Agriculture conversions have significantly impacted vegetation including valley bottom grasslands, shrublands, cottonwood dominated riparian areas and brush laden draws. It was estimated that 70 percent of the wetlands within the scablands were drained in the early 1900s for agriculture. Tillage has accelerated erosion and increased sediment loads to streams. The hill tops of the Palouse have lost all or most of their wind-blown loess topsoil through the combined tillage and water action (Kaiser 1975). Tillage often occurs up to the stream edges in many places leaving no buffer between croplands and streams.

The completion of the four major Corps dams between 1961 and 1975 provided better and more reliable navigation to Lewiston-Clarkston, which provided more reliable shipment of numerous products. However, the region, in general, has largely remained rural, with agriculture being the primary land use.

Conversion of floodplains and riparian forest buffers to agricultural fields and residences, and channel modifications including straightening, diking, and bank armoring have dramatically altered the Palouse, the lower portions of the Tucannon River as well as smaller systems such as Alpowa and Deadman Creeks. Logging, conversion of perennial grasslands to annually planted dry cropland, and grazing have led to increased runoff and erosion of fine sediment throughout the region (Kuttle 2002).

Historically, much of the farming consists of winter-spring rotations with clean cultivated summer fallow. Today, when fallow operations are used, chemical fallow instead of mechanical fallow is often implemented to reduce erosion potential. No-till farming is also used to reduce erosion. It includes using specialized equipment to place the fertilizer and seed directly into the previous year's crop residue without performing prior tillage operations. It is not uncommon to see a no-till operation replace conventional practices in one leg of the rotation (Gilmore 2004).

In areas where tillage is used in the highly erodible wind-blown loess soils, there can be the formation of ephemeral gullies when runoff is concentrated and leaves fields with a velocity that cuts a ditch. When gully erosion does occur, sediment delivery is high. This type of erosion is more problematic in conventionally farmed fields and less likely to occur when crop residues remain. While a gully would be groomed between crops, it can re-form. Also, many small, intermittent streams have been ditched, straightened and riparian vegetation removed for conversion to drainage ditches.

Deeper soil sites were mostly converted to agriculture while drier grasslands and canyon grasslands, those with shallower soils, steeper topography, or hotter, drier environments, were more likely to be grazed. Erosion is accelerated in the grazed riparian areas due to stock trails at the water's edge, denuded streambanks and unarmored cattle crossings. The Palouse was more affected by grazing than other types of grassland such as in the Great Plains. Not only was the type of grass in the Palouse not developed under the pressure of close grazing, but the moisture pattern with a summer drought made the grasses vulnerable to late spring or early summer grazing (Gilmore 2004).

Private logging began in the 1880's at low levels. The major boom took off in 1905 with the creation of the Potlatch mill that closed in the early 1980s. Logging activity on National Forest System lands and associated road construction was at its peak in the 1960s and 1970s, and has tapered off considerably (Gilmore 2004).

In the Palouse and Rock watersheds, approximately 85 percent of the riparian areas within the watershed are estimated to be directly effected by human land use (agricultural activities, grazing or urban development). Healthy riparian vegetation is limited, reducing or eliminating a buffer that could prevent the soil erosion from reaching the streams as sedimentation. However, approximately 10 percent of the farmable cropland is estimated to be enrolled in the CRP where farmland is left idle for a period of at least 10 years while being maintained in a permanent cover crop of grass, or a mixture of grass and legumes (Gilmore 2004).

Over time, the streams have undergone change in the flow regime, bed and riparian structure, and water quality. In the Pataha, the changes seem to have occurred in the decades following establishment of the agricultural economy. In the Tucannon drainage, the changes were a combination of land use and extreme floods. The wooded riparian zones were replaced with open zones in the agricultural areas resulting in diminished shade and less stable banks. Many of the changes in the upper half of the watershed occurred during the extreme floods in the 1960’s and 1970’s and most of the changes in the lower watershed pre-date these events (Covert et al. 1995).

The sinuosity of the Tucannon River decreased by 50 percent and the channel length was decreased between 7 to 20 percent from 1937 to 1975 leading to channel braiding and decreased bank stability (Kuttel 2002 and Hecht 1982).

In recent years, the listing of certain species of salmon and steelhead under the ESA coupled with the loss of soils from farming areas has provided the impetus for stream restoration and stabilization, plus the need to implement better farming techniques that conserve and retain soils. In general, the Palouse hills area has been characterized as one of the “worst” for soil erosion in the United States (USDA Soil Conservation Service et al. 1984). Several conservation districts have taken a lead in soil conservation efforts. As such, sediment inputs to local tributaries could decrease in the future as these techniques become more universal and as habitat (such as riparian zones) is reestablished and stream banks become more stabilized.

Table 40 presents some ratings, developed by the Interior Columbia Basin Ecosystem Management Project (Quigley and Arbelbide 1997), which can be used as overall indices of the relative level of disturbance in each watershed within the geographic area. The measures relate to the degree of hydrologic disturbance in forest and rangeland environments (based on the level of surface mining, dams, cropland conversion, and roads) and the degree of riparian disturbance in rangeland environments (based on the sensitivity of streambanks to grazing and the sensitivity of stream channel function to the maintenance of riparian vegetation).

Based on these ratings, the broad generalization can be made that the overall level of disturbance to the non-forested land is high. The forests were not rated because they make up less than 20 percent of the watersheds.

Table 40. Hydrologic Disturbance Rating of Forest and Rangeland Environments and Riparian Disturbance Rating of Rangeland Environments Relative to the Entire Columbia Basin by Watershed (4th-field HUC) within the Lower Snake River Basin Geographic Area

Watershed Name	Hydrologic Disturbance Rating of Forest Environments	Hydrologic Disturbance Rating of Rangeland Environments	Riparian Disturbance Rating of Rangeland Environments
Palouse	Unclassified	High	High
Rock	Unclassified	High	High
Tucannon	Unclassified	High	High
Lower Snake	Unclassified	High	Mod

1\ watersheds with less than 20 percent forest were not classified.
Source: Maps 2.34, 2.35, and 2.36, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings

9.3 SEDIMENT SOURCES AND YIELD

9.3.1 Overview Studies on Erosion, Mass Wasting, and Sedimentation

In this section, ratings and other results from a number of overview studies that were conducted across the entire Columbia River basin or over larger areas are presented for perspective and comparison purposes. The methods behind these studies are summarized briefly below and in more detail in Section 4.1.

The Interior Columbia Basin Ecosystem Management Project, conducted by the Forest Service and the BLM (Quigley and Arbelbide 1997) developed various soil erosion, mass failure, and sediment hazard ratings for nonpoint sources for each watershed, relative to all Columbia Basin watersheds. The key ratings are shown for the Lower Snake and tributaries basin in Tables 41 and 42.

Table 41. Soil Erosion, Mass Failure, and Sedimentation Measures within the Lower Snake River Basin Geographic Area Relative to the Entire Columbia Basin by Watershed

Watershed Name	Surface Soil Erosion Hazard	Earth Flow Hazard	Debris Avalanche Hazard	Sediment Delivery Potential	Sediment Delivery Hazard
Palouse	High	Low - Mod	Low – Mod	Mod - High	Low - Mod
Rock	High	Low - Mod	Low	Low	Low - Mod
Tucannon	High	Low - Mod	Low – Mod	Low	High
Lower Snake	High	Low - Mod	Low	Low	Low - Mod

Source: Maps 2.10, 2.11, 2.12, 2.13, and 2.15, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

Table 42. Road Erosion Hazard and Road Sediment Delivery Hazard within the Lower Snake River Basin Geographic Area Relative to the Entire Columbia Basin by Watershed

Watershed Name	Road Erosion Hazard	Road Sediment Delivery Hazard
Palouse	High	Low
Rock	High	Low
Tucannon	High	Mod - High
Lower Snake	High	Low

Source: Maps 2.16 and 2.17, Volume I, in Quigley and Arbelbide (1997). See Section 4.1 of this report for a description of the methods behind the ratings.

NMFS (Baker et al. 2005) has developed a model for estimating increases in erosion rates relative to historical, pre-settlement rates. Based on this study, erosion rates in the forested areas of the Palouse and Tucannon watersheds have not changed much and are 1 to 1.5 times historical rates. The erosion rates on non-forested land in the eastern half of the non-forested Palouse, Rock, and Tucannon watersheds ranges from 5 to 10 times that of historical rates. In the western half of those watersheds (including scablands) it ranges from 1.5 to 5 times the historical rate. The Lower Salmon Watershed was estimated to have erosion up to 3 times the historic rate.

The USGS developed a landslide overview map (Radbruch-Hall et al. 1982). This map delineates areas where large numbers of landslides have occurred and areas which are susceptible to landsliding in the conterminous United States. Within the Lower Snake River Basin geographic area, no areas with a moderate to high incidence of past landslides or susceptibility to future landslides were identified.

A NRCS analysis of cropland in the conterminous United States found that the all four watersheds showed extensive areas with excessive erosion on highly erodible lands. The western portion of the Lower Snake River watershed also includes areas of non-highly erodible land, also with excess erosion (NRCS 2000).

9.3.2 Subbasin Studies

A Southeast Washington Cooperative River Basin Study (USDA Soil Conservation Service et al. 1984) investigated sediments and erosion for the Snake River drainage and all tributaries south of the Snake River in Washington State. The study found that soil erosion and sedimentation on cropland is the most serious issue. Average erosion rates on forested land (0.37 tons/acre/year) and rangeland (0.5 tons/acre/year) are notably less than that of cropland (8 tons/acre/year). Of the 10.3 million tons soil eroded per year, the study estimated that 1.7 million tons enters the streams as sediment. Over 90 percent results from sheet and rill erosion on cropland. The erosion rates are highest in areas where mean average precipitation is 15 to 18 inches per year. It is also highest on the top and steeper northeast side of the Palouse type hills created by wind-blown loess, the most erodible parts of these hills. In forested areas, only road and streams have average annual erosion or sediment rates greater than one ton/acre. The result is a very close correlation between road density and sediment yield in forested areas; sediment rate in tons per square mile per year is nine times the road density. Despite that, the largest total yield of erosion in forested areas was from undisturbed areas (USDA Soil Conservation Service et al. 1984).

Sediments are monitored by several agencies at various sites. As part of their long-term Ambient Water Quality Monitoring Program, WDOE has water quality monitoring stations in the watershed and the data are available on-line at:

http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html#4

USGS has water quality and flow measurement stations in each of the watersheds and also has the data available on-line: http://waterdata.usgs.gov/nwis. In addition, the USGS National Aquatic Water Quality Assessment (NAWQA) Program for the Central Columbia Plateau (http://wa.water.usgs.gov/projects/ccyk/summary.htm) provides information and publications regarding sediment, nutrients, and other water quality parameters in the Palouse River. The Pomeroy Ranger District of the Umatilla National Forest has been monitoring water quality and the results are not routinely published. WSU has monitored water quality for conservation districts.

The following discusses the existing information for specific watersheds. While there are similarities among the Palouse, Rock, Tucannon, and Lower Snake watersheds, they have been often studied separately. The tributaries also influence the sediment in different reservoirs due to the location of their confluence with the Snake River. Therefore, this section is divided into a discussion of the tributaries of the four major reservoirs upstream of the Snake River mouth: Lower Granite Reservoir, Little Goose Reservoir (Lake Bryan), Lower Monumental Reservoir (Lake Herbert G. West), and Ice Harbor Reservoir (Lake Sacajawea).

Sediment Sources and Transport into Lower Granite Reservoir

The Snake and Clearwater Rivers upstream of their confluence provide a large amount of sediment to the upstream end of Lower Granite Reservoir. This deposition requires periodic dredging by the Corps to maintain the navigation channel and sufficient freeboard on local levees to prevent flooding. Sediment input and transport to this area are discussed in separate sections. The three main tributaries to Lower Granite Reservoir are Alpowa Creek, Wawawai Creek, and Steptoe Canyon Creek. The following describe information on each of these.

Alpowa Creek

Alpowa Creek originates from springs at the northeast end of the Blue Mountains. The mainstem is the only creek in this watershed that maintains perennial flow (Pomeroy Conservation District 2004). Major sediment transport occurs during rain-on-snow events that contribute to the extensive alluvial fan at the mouth of Alpowa Creek (Kuttle 2002). The *Salmonid Habitat Limiting Factors Water Resource Inventory Areas 33 (Lower) and 35 (Middle) Snake Watersheds, and Lower Six Miles of the Palouse River* (Kuttle 2002) provides a detailed description of habitat conditions in various segments of Alpowa Creek. Key characteristics described that would affect sediment input and transport include riparian habitat conditions, water diversions, streambank condition, substrate embeddedness, large woody debris, and width/depth ratio. Similarly, the *Lower Snake Mainstem Subbasin Plan* (Pomeroy Conservation District 2004) also describes characteristics of the Alpowa Creek watershed.

The Soil Conservation Service (USDA Soil Conservation Service et al. 1984) has indicated that cropland in the Alpowa drainage had some of the highest erosion rates in southeastern Washington. Indications of this are demonstrated by the large alluvial fan at the mouth of Alpowa Creek where it flows into Lower Granite Reservoir (Spangrude 2004). The Soil Conservation Service provided estimates of the erosion and soil loss that occurs in this drainage.

Other information on sediment input and transport in Alpowa Creek is limited to the summary documents by Kuttle (2002), Pomeroy Conservation District (2004), and water quality monitoring reports (Pomeroy Conservation District (2001). In the latter report, TSS have been sampled from 1999 through 2001. The general observation made in this report was that sediment levels were decreasing, likely as a result of implemented conservation practices.

The Corps also monitors sediment deposition in Lower Granite Reservoir at a number of different “ranges” (Corps 2002). The primary reason for gathering this data is to determine deposition rates in relation to the maintenance of the navigation channel.

Steptoe Canyon and Wawawai Creeks

Little information is available on either of these drainages. The Lower Snake Mainstem Subbasin Plan indicates that a “large depositional fan” exists at the mouth of Steptoe Canyon Creek (Pomeroy Conservation District 2004). This would tend to indicate that soil erosion is occurring upstream. In addition, Spangrude (2004) presented a picture of this alluvial deposit in a public meeting in March 2004.

The *Salmonid Habitat Limiting Factors Water Resource Inventory Areas 33 (Lower) and 35 (Middle) Snake Watersheds, and Lower Six Miles of the Palouse River* (Kuttle 2002) provides a detailed description of habitat conditions in various segments of Steptoe and Wawawai creeks. Key characteristics described that would affect sediment input and transport include riparian habitat conditions, water diversions, streambank condition, substrate embeddedness, large woody debris, and width/depth ratio. Kuttle indicates that a major flash flood during late summer 2001 resulted in scoured out portions of the channel and large deposits of gravel in other areas of Steptoe Canyon Creek. Livestock grazing in some areas of Steptoe Canyon Creek has also eroded streambanks. In Wawawai Creek, the streambanks appear more stable (Kuttle 2002).

Sediment Sources and Transport into Little Goose Reservoir (Lake Bryan)

The main tributaries or drainages to the Little Goose Reservoir (Lake Bryan) are Deadman Creek, Almota Creek, Penawawa Creek, New York Gulch, and Dry Gulch.

<u>Deadman Creek</u>

Major sediment transport occurs during rain-on-snow events, which are contributors to the alluvial fan at the mouth of Deadman Creek. Major storms often carry “immense” fine sediment loads in both Meadow and Deadman creeks (Kuttle 2002).

TSS were surveyed by WSU for Pomeroy Conservation District for 2003 to 2005 for sites on Pataha, Deadman and Meadow Creeks. Generally the samples taken were less than 10 mg/l, but at each sample sites there were individual readings with notable individual day spikes. Lower Deadman showed readings of 35 and 4000 mg/l at the two sampling sites and 200 mg/l were the high individual readings at sites on Meadow Creek (WSU 2005).

The *Salmonid Habitat Limiting Factors Water Resource Inventory Areas 33 (Lower) and 35 (Middle) Snake Watersheds, and Lower Six Miles of the Palouse River* (Kuttle 2002) provides a detailed description of habitat conditions in various segments of Deadman Creek. Key characteristics described that would affect sediment input and transport include riparian habitat conditions, water diversions, streambank condition, substrate embeddedness, large woody debris, and width/depth ratio. Similarly, the Lower Snake Mainstem Subbasin Plan (Pomeroy Conservation District 2004) also describes characteristics of the Deadman Creek watershed.

Sediment Sources and Transport into Little Goose Reservoir (Lake Bryan)

<u>Almota Creek, Penawawa Creek, New York Gulch, and Dry Gulch</u>

Very limited information relative to sediment is available on these drainages. The Pomeroy Conservation District (2004) identified roads, channelization, and agricultural land uses next to streams as limiting factors for Almota Creek. Also, Kuttle (2002) describes limiting factors in Almota Creek. However, no information was found on Penawawa Creek, New

York Gulch, or Dry Gulch. Actual measurements of sediment input or transport were not found.

Sediment Sources and Transport into Lower Monumental Reservoir (Lake Herbert G. West)

The main tributaries or drainages to the Lower Monumental Reservoir (Lake Herbert G. West) are the Palouse and Tucannon Rivers, along with smaller drainages including Alkali Flat Creek, and Fields Gulch.

<u>Palouse/Rock Watershed</u>

McCool and Papendick (1975) reported that sediment concentrations in the Palouse area are extremely variable on a daily, seasonal and annual basis. Runoff events of short durations (few days) can account for large percentages of sediment in a year and can even equal 4 to 5 times other years. Sampling programs of just a few years or of low-frequency can be misleading and may explain the wide variation in results of the various reports on sedimentation.

In Idaho, the South Fork Palouse River and several tributaries of the mainstem are on the 303(d) list for sediment. The South Fork of the Palouse River is listed from its headwaters to the Idaho-Washington border for sediment and other pollutants (bacteria, flow alteration, habitat alteration, nutrients, and temperature). Turbidity and TSS were monitored 27 times in one year at four sites. Turbidity averaged between 27 and 34 NTU and TSS averaged between 6 and 37 mg/l at the sites (Clark 2003). Deep, Hanigan, Cold, Flatter, Rock Creeks are tributaries to the mainstem Palouse River in Idaho on the 1998 303(d) list for sediments. The assessment documented by IDEQ in 2005 confirmed that they did not meet Idaho State sediment requirements. The monitored sediment load was determined to be 7,041, 1,452, 662, 1,223, and 148 tons per year in each tributary, respectively. Background sediment load, calculated using the RUSLE model, was determined to be 234, 62, 26, 219 and 12 tons per year, respectively. The resulting percent reductions required by the TMDL, range from 46 to 96 percent. In general, sediment measured adjacent to agricultural lands was higher than adjacent to forest lands in these streams (Henderson 2005). The mainstem of the Palouse was not listed, possibly because it supports beneficial uses.

In the Idaho monitoring report for 303(d) analysis of the South Fork of the Palouse and the tributaries to the mainstem in Idaho, Clark commented that based on visual assessments, TSS rates, and turbidity levels, the South Fork Palouse River, Hatter Creek, Flannigan Creek, Gold Creek, and Deep Creek seem to have the highest rates of bank erosion. Hatter and Flannigan also appear to have more cattle accessing the stream than any other stream in the watershed (Clark 2003).

While several streams in the Palouse/Rock watersheds are on the Washington 303(d) list, none are listed for sediment. Suspended sediments in the Palouse River at Hooper, Washington, were found to have declined from an average of 2.8 tons/acre-foot in 1962 to 1971 to 1.4 tons/acre-foot from 1993 to 1996 (Ebbert 1998).

A Washington State water quality report in 1995 indicated that the water quality in the Palouse is degraded with temperature, fecal coliform and pH frequently exceeding water quality criteria at the mainstem. Sediments and nutrients were noted as being high at all monitoring stations (Pettelier et al. 1995). Water quality is monitored monthly at several stations in the Palouse watershed. The 2003 and 2004 results for turbidity at Hooper, WA (furthest downstream station) ranged from 2 to 70 NTU and for suspended solids ranged from 3 to 66 mg/l.

Boucher (1970) reported the discharge-weighted, mean concentration of suspended sediment in the Palouse at Hooper, Washington from 1961 to 1965 to be 2,970 mg/l and the average annual sediment discharge to the Snake River to be about 1.5 million tons per year. The sediment yield ranged from 5 tons per square mile from the western part of the watershed to 2,100 tons per square mile in the central part and 460 to 1,000 tons per square mile in the eastern part. The high yield in the central part was considered to be the result of low vegetal cover, the wind-blown loess soils, and rapid run-off during winter storms. It was reported that approximately 81 percent of the sediment transport occurred during storm runoff from 1961 to 1965 and the highest concentrations occurred during the winter. Land use was considered to have had the greatest effect on increasing sediment yields. The study showed average annual soil loss in the area to be 14.2 million tons (Boucher 1970).

Erosion is considered to be a serious agriculture sustainability and productivity issue and has been the subject of studies. Erosion in some areas of the Palouse is “enormous” and the Palouse has been called one of the most erosive areas in the United States (Boucher 1970). The United States Department of Agriculture (USDA) estimated the average annual rate of soil erosion in the Palouse from 1939 through 1977 to be 14 tons/acre on cultivated cropland. While not all eroded soils reach the streams, loss of riparian vegetation makes it more likely that it will (Henderson 2005). A Kaiser study (1975) of soil loss due to erosion and its impacts on farming productivity showed that in traditional tillage areas, the Palouse hills eroded unevenly with the steeper north and east sides eroding more than the south and west sides (up to 30 and less than 10 tons per acre respectively).

According to the Palouse Cooperative River Basin Study (SCS 1978), soil loss by water induced erosion within the watershed ranges from moderate (with an average soil loss between 7 to 10 tons per acre per year) across much of the watershed to severe (with an average soil loss of 10 to 13 tons per acre per year). Erosion rates on rangeland and forested areas is considerably lower (up to 1 ton/acre) than that of cropland (20 to 30 tons/acre are common). Erosion is highest in the middle of the watershed.

Erosion and sediment delivery were estimated to be notably lower for pasturelands managed under conventional practices. An estimated 0.9 tons/acre/year erosion can occur on pastureland with a 10 percent sediment delivery ratio for sheet and rill erosion and 0.5 tons/acre/year for ephemeral gully erosion with a 60 percent sediment delivery (Rassmussen et al. 1995).

<u>Tucannon Watershed</u>

While several stream segments in the Tucannon watershed are on the Washington 303(d) list, none are listed for sediment. In a watershed briefing paper published by the WDOE, the water quality in the Tucannon was considered good when compared to the Palouse and Walla Walla systems. However, it was stated that nutrients, sediments and temperatures were high relative to statewide conditions and that while not highly significant, there was an increasing trend noted in suspended sediments (data not included) (Pettelier et al. 1995).

Water quality is monitored monthly by the WDOE at stations in the Pataha and the Tucannon River watershed. The results at Powers, WA (furthest downstream station on the Tucannon River) for 2003 and 2004 ranged from 1 to 32 NTU for turbidity and ranged from 2 to 98 mg/l for suspended solids (WDOE 2006).

Forest Service monitoring, supplemented by WSU, recorded turbidity and suspended solids data in the upper third of the Tucannon watershed. The turbidity data was less than 15 NTU at all stations monitored, except for a peak reading of 101 NTU in the middle reaches. The suspended solids were below the Forest Service-recommended standard of 80 mg/l. The readings were below 35 to 50 mg/l in spring months in the lower reaches of the National Forest to below 10 mg/l in other months and were in the 30 to 55 range all year at the upstream stations. Downstream of the National Forest, in the lower Tucannon, turbidity measurements were below 30 NTU except for a few measurements that ranged to approximately 85 NTU.

WSU and WDOE each have recorded TSS concentration in the Tucannon watershed. The summary of suspended sediments monitoring from 1979 to 2001 at the lowest reach of the river (from Kelly Creek confluence to the mouth) showed an average monthly reading from under 20 to approximately 210 mg/l. The mean monthly TSS recorded by WSU in this reach were generally below that recorded by WDOE and well below the Forest Service recommended standard of 80 mg/l. The mean TSS recorded by WDOE exceeded the recommended standard in 4 out of 12 months (Middle Snake Watershed Planning Unit 2005).

The combined annual sediment yield to streams for the entire Tucannon watershed was determined to be approximately 170,000 tons per year with most severe sedimentation issues in the lower third of the watershed, and noticeable lower severity upstream (Columbia Conservation District 2004).

In the Soil Conservation Service Southeast Washington Study (1984), the Tucannon Watershed was determined to have a high erosion rates on cropland at approximately 7 tons/acre/year compared to the average of 8 tons/acre/year in southeast Washington. While this is below average in the study, it was higher than the erosion for other tributaries to the Snake (the study included Walla Walla subbasin which was about 50 percent higher due to different conditions) (SCS et al. 1984).

A report was prepared for the SCS in 1982 (Hecht et al. 1982) on sediment transport and water quality in the Tucannon watershed. It was noted that a disproportionate amount of the sediment load originates in the lowland portions of this watershed. The portion of sediment that is bedload sediment is normally much smaller in the Tucannon watershed and in southeast Washington than in other areas. The lowest unit yields (0.14 and 0.27 tons per acre) were in the most upstream stations and in the lower watershed the yields ranged up to about 1.4 tons per acre. The total annual yield in 1980 for suspended sediment was estimated at 146,141 tons of sediment at the lowest station (approximately a mile from the Snake River) in a year without an extreme event (Hecht et al. 1982). In the Pataha Creek Watershed Plan, it was noted that in an unpublished SCS report, Pataha River sites had estimated erosion of 649,413 tons per year and total sediment delivery to the Tucannon River of 77,930 tons per year (Pomeroy Conservation District 1998).

Seasonal variations in suspended-sediment concentrations in the Tucannon watershed were described as winter storm runoff, peak snowmelt, and summer cloudbursts. Runoff from the first couple storms of winter often transports significantly larger concentrations of sediment than later events. For a given discharge, snowmelt transport rates are less than transport rates during winter storms. It was noted that the transport rates at flood stage are 10 times or more larger in this region than elsewhere in the United States and that the rate of velocity increase with discharge is among the largest values reported in literature. Less than 10 percent of the sediment yields occur at discharges less than twice the yearly mean (Hecht et al. 1982).

TSS were surveyed by WSU for Pomeroy Conservation District for 2003 to 2005 for sites on Pataha, Deadman and Meadow Creeks. Generally the samples taken were less than 10 mg/l, but at each of the sample sites there were individual readings with notable individual day spikes. Lower Deadman showed readings of 35 and 4,000 mg/l at the two sampling sites. Pataha showed 300, 400 and 700 mg/l at different stations, and 40 and 200 mg/l were the high individual readings at sites on Meadow Creek (WSU 2005).

Alkali Flat Creek and Fields Gulch

Alkali Flat Creek and Fields Gulch were not evaluated by Kuttle (2002). However, this author did provide a few details about Alkali Flat Creek. For example, he indicated that the Soil Conservation Service in 1984 found that sheet and rill erosion of cropland in this watershed carried 79,000 tons of fine sediment per year into the Snake River. In the Soil Conservation Service et al. (1984) study, the rate of erosion for cropland in the Alkali Flat Creek area was reported as below average for the area, 5 tons/acre/year compared to 8 tons/acre/year for watersheds south of the Snake River.

Sediment Sources and Transport into Ice Harbor Reservoir (Lake Sacajawea)

There are only two streams or drainages into Lake Sacajawea. These are Walker Canyon Creek and an unnamed tributary. Neither stream is referenced in Kuttle (2002) or Pomeroy Conservation District (2004). In the Soil Conservation Service et al. (1984) study, the rate of erosion for cropland in the Lower Snake Watershed was reported as below average for the area, 5 tons/acre/year compared to 8 tons/acre/year for watersheds south of the Snake River.

9.4 MANAGEMENT PRACTICES AND RESTORATION PROJECTS

The management practices in Idaho that affect the Idaho portion of the Palouse watershed are described in the Clearwater River subbasin section of this report (Section 6.4).

Washington's nonpoint source pollution control efforts for agriculture focus primarily on voluntary actions of growers and producers. Assistance and incentives from government agencies can be coupled with enforcement to target producers not cooperating with efforts to improve water quality. Local conservation districts, the NRCS, and WSU Cooperative Extension provide technical assistance for implementing BMPs in agriculture as defined in the NRCS field office technical guides (FOTG). Incentives include financial assistance for implementing farm plans and BMPs through the NRCS' EQIP program and reducing erosion and sediment through the lease or purchase of riparian buffer areas through the CREP program. One EQIP wind erosion project in Franklin and Benton Counties pays farmers to increase residue left on their fields. Erosion and sediment problems that are not voluntarily resolved can be directed to WDOE through complaints (Green et al. 2000).

The Washington State standards for turbidity are relative to background turbidity. They are an increase of less than 5 NTU increase for background turbidity of less than or equal to 50 NTU and less than 10 percent increase when the background it greater than 50 NTU [Washington Administrative Code (WAC) 173-201A]. There are no published standards for TSS in Washington State. However, the USFWS (1995, Introduction to Fish Health) suggests the upper limit of continuous exposure for the optimum health of salmonids is 80 mg/l.

The WDFW developed standards for managing and protecting state-owned lands used for agriculture or grazing. These standards are known as House Bill (HB) 1309 Ecosystem Standards for State-Owned Agricultural and Grazing Land. To comply with this bill, the WDNR has integrated a Resource Management Plan in all new or revised agricultural leases. The plan is designed for specific site conditions and generally minimizes land use activities that contribute to the deterioration of the ecosystem (Green et al. 2000).

Forestry in Washington is governed by the Forest Practices Act and regulations related to all aspects of forest practices. A permit from WDNR is required for timber harvest on forestlands in the state. The Forest Practice Rules specify the type and amount of activities that can occur on forest lands. The Rules were revised in 2002 and specify Riparian Management Zones (RMZs) for eastern Washington. The RMZs range from 75 feet to 130 feet from the bank full width of the stream, depending on the class of the stream and the width of the river. In all cases, the core zone is 50 feet. No harvest or construction is allowed in the core zone with few exceptions when necessary. Trees cut for or damaged within the core zone are to be left on site and those cut for road construction to cross a stream can be removed. Outside the core zone, but still within the RMZ, limited activities are allowed and there are requirements for the number of trees to be left to maintain proper functioning of the streams (WDNR 2002).

Improvement and restoration projects are funded and managed by many organizations. The NRCS, in conjunction with locally based conservation districts, also provide technical assistance and education to small timberland owners. There is also the Forestry Incentive Program, administered by the NRCS and WDNR to provide technical assistance on forest production and habitat planning.

NOAA has developed a website with an interactive mapping tool that provides information about restoration projects in the study area (http://www.nwr.noaa.gov/Salmon-Recovery-Planning/PCSRF/). This website provides a broader view of the funding for salmon recovery and encompasses not only the efforts of the Washington IAC salmon recovery efforts, but also the efforts in Oregon and Idaho.

Another funding entity is the BPA, which funds salmon recovery and habitat projects throughout the Columbia River Basin. Information about BPA's fish and wildlife projects is available through Streamnet or the Columbia River Basin Fish and Wildlife Authority at the following respective sites:

http://www.streamnet.org/

http://www.cbfwa.org/fwprogram/maps.cfm

The 2000 to 2002 projects of the Columbia River Inter-Tribal Fish Commission (CRITFC) Tribes (funded by PCSRF), includes some that are in the study area and would affect sediments (CRITFC 2002). The Spirit of the Salmon Plan (CRITFC 1995) lists plans for each watershed to address fish habitat. Many of these projects would reduce sediments because they are designed to stabilize or restore habitats (e.g., streambanks).

In addition, the Corps has recovery or enhancement projects in the Snake River basin that are funded under various plans including the Lower Snake River Compensation Plan (Corps 1975) and its supplement (Corps 1996) which provides terrestrial and aquatic mitigation in response to the development of the Corps' four dams on the lower Snake River, and other funding through sources such as the Water Resources Development Act (particularly Sections 206 and 1135).

<u>Alpowa</u>

There are a wide variety of management approaches and processes for reducing sediment input from Alpowa Creek. These are summarized in the Lower Snake Mainstem Subbasin Plan (Pomeroy Conservation District 2004) and the Southeast Washington Cooperative River Basin Study (USDA Soil Conservation Service et al. 1984). In addition, the IAC's Salmon Recovery Funding Board lists a number of projects on its website that are specifically focused on sediment reduction in Alpowa and other local streams. An example of this is reported by the WDOE (2005) in a joint effort with local landowners, the Pomeroy Conservation District, and the local NRCS office. The project in this example was fencing along 10 miles of the upper Alpowa Creek drainage to exclude livestock coupled with plantings of thousands of native trees and shrubs to help stabilize banks, thus reducing erosion. The CREP, NRCS Soil and Water Conservation Assistance Program (SWCA), and the WDOE Centennial Clean Water Fund provided funding for the project.

<u>Deadman Creek, Steptoe Canyon, Wawawai Creek, Alkali Flat Creek, and Field Gulch</u>

There are a wide variety of management approaches and processes for reducing sediment input from Deadman Creek, Alkali Flat Creek, and Field Gulch. These are summarized in the *Lower Snake Mainstem Subbasin Plan* (Pomeroy Conservation District 2004). For example, the Pomeroy Conservation District has implemented conservation practices to reduce erosion from upland croplands. This broad-based program [funded through the Interagency Committee (IAC) Salmon Recovery Funding Board (SRFB)] includes practices such as changing crop rotations, reducing conventional summer fallow programs, and conversion from conventional tillage to direct seeding (IAC 2005).

<u>Palouse</u>

Loss of soils in farming areas has been the primary subject of research and impetus for implementing better farming techniques that conserve and retain soils. All but the lowest 6 miles of the mainstem are blocked from access by salmonids. The conservation districts have taken a lead in soil conservation efforts and stream restoration and stabilization. As such, sediment inputs to local tributaries may decrease in the future as improved farming techniques become more universal and as riparian zones are reestablished and stabilize stream banks.

A USDA funded study (USDA Cooperative State Research, Education, and Extension Services 2004) is being implemented in Paradise Creek in the eastern Palouse watershed to understand the effectiveness of conservation practices at the watershed scale. The study is funded through 2007 and is intended to provide an understanding of sediment transport and cumulative effects.

Tucannon

Recommendations in the Limiting Factors report for WRIA 35 include improving riparian vegetation and reducing erosion. Specifically, the erosion reduction suggests implementing no-till/direct seed farming methods on as many acres as possible (Kuttle 2002).

The critical limiting factor to salmonid fish production in the Tucannon watershed was determined to be maximum water temperature. Other factors included: riparian function, LWD, hatchery fish outplants, anthropogenic confinement, fish pathogens, harassment/poaching, embeddedness, salmon carcasses, and pools (Kuttle 2002). Most restoration efforts have the potential to decrease sediment inputs to the stream. There are a variety of ongoing restoration activities in the state of Washington that are implemented in the Tucannon Watershed.

Since 1996, a total of 684 projects were implemented in the Tucannon watershed to improve fish habitat. Of those, 34 percent specified a general focus of sediments. Another 8, 9 and 6 percent were for channel stability, temperature, and riparian function, respectively and likely positively affected sediment (Columbia Conservation District 2004).

9.5 SUMMARY OF PRELIMINARY CONCLUSIONS

Based on this review of available information, a few preliminary conclusions can be made regarding opportunities for sediment reduction. It appears that the most promising watersheds for reduction efforts would include the Palouse, Rock, and Tucannon. In these watersheds, it appears that agricultural and grazing areas have the greatest potential for improvements. Restoration of degraded riparian areas, projects to limit field erosion and delivery to streams in agricultural/grazing areas, and preventing road failures and minimizing road erosion appear to be the projects with the highest potential for success. Most of these opportunities are on private lands.

10. PRELIMINARY RECOMMENDATIONS FOR FURTHER STUDY

This section presents preliminary recommendations representing various options for further study, based on the initial information and data gathering efforts. These options can be conducted sequentially or in groups and will depend on available funding levels.

Options for Further Study

Conduct a screening effort using the references and GIS information gathered in the initial effort to identify the following:

- Watersheds and subwatershed with highest sediment production.
- Identify whether production is likely from natural sources or is the result of land use and other human factors.
- From this information, make an initial prioritization of watersheds/ subwatersheds to investigate further (this does not mean medium and lower priority watershed will not be investigated, but that resources can initially be targeted to the highest priority watersheds assuming that resources (staff and funding) are limited.

Further organize and evaluate the many widely dispersed and often short-term sediment transport measurements that have been conducted by various parties throughout the watershed to determine additional information that is available to support identification of sediment delivery from the various watershed and subwatersheds

- USGS 1980 study (Jones and Seitz 1980).
- USGS daily suspended sediment measurements.
- PACFISH/INFISH Biological Opinion Monitoring (PIBO).
- State Water Quality monitoring programs.
- Suspended and bedload sediment measurements from the Snake River Basin Adjudication effort.
- Project-specific measurements from the Forest Service and other agencies that are available only on file in local offices.
- Assess the applicability of the measurements and use this to help identify needs for the sediment transport monitoring program.

Conduct a multi-year sediment transport monitoring program similar to the USGS 1972 to 1979 effort (Jones and Seitz 1980).

- Effort should be concentrated on basins with the highest potential for sediment delivery from a screening effort.
- Bedload sampling, which is expensive and time consuming may not be necessary as the 1980 study showed bedload was a relatively minor portion, averaging about 5 percent, of the total sediment load.
- The effort should be conducted again at both the Anatone, Washington (Snake River) and Spalding, Idaho (Clearwater River). It will be of particular interest to see if the load on the Snake River has lessened compared to the Clearwater. For the 1972 to 1979 period of the previous study, the load on the Snake was approximately 4 times the load on the Clearwater. Recovery of high sediment production areas in the South Fork of the Salmon could possibly have reduced the contribution from the Snake.
- Identify other potential sites to extend the sampling effort to, develop and implement the program at these additional key sites.

Develop an initial sediment budget for the study area to the extent possible with existing information supplemented by field work.

- Utilize reservoir sedimentation information and references such as the USGS 1980 study (Jones and Seitz 1980) to identify the total sediment inflow to the system. For example, sediment transects are completed every 3 years in Lower Granite Reservoir by the Corps (Les Cunningham, Corps, Walla Walla District, personal communication, 2006). The results of these evaluations are filed at the Walla Walla District. In addition, other major documents (see Appendix D) address sediment loading and ranges in the Lower Granite Reservoir (and other lower Snake River reservoirs).
- Utilizing the information gathered to develop a procedure that allocates the sediment production to the various watersheds and subwatersheds based on factors such as soils, geology, topography, cover, land use and mass wasting. Additionally, other sediment transport measurements, if identified, should be used to calibrate and assist in the process.
- Account for non-contributing areas above lakes.
- If practical, the procedure should assign the sediment production to various erosion types such as: sheet and rill erosion, gullying, mass wasting, channel instability (bed and bank erosion) and wind erosion.

- The procedure should also assign the erosion to various land use and land management practice areas.
- Account for instream factors that might delay or limit delivery of upstream sediments.
- This effort will likely require some stratified random sampling of various aspects of the system such as channel instability.

Utilize the results of the sediment budget to reassess priority targets by location and land use and management practices.

- Develop strategies for addressing sediment production and delivery from the target areas.
- Review effectiveness of efforts already underway on these or similar lands.
- Identify administrative authorities to actually fund and implement efforts that will bring about improved conditions.
- Develop additional measures that could be used to address key problems.

Estimate potential for reduction in sediment loading to the Lower Snake Reservoirs from application of the measures.

- Estimate potential sediment reduction from the actions.
- Develop time frame for reduction.
- Determine if there would be a reduction or increase in sediment load to the Lower Snake Reservoirs over time (factors such as already implemented land management and land use practices as well as historic and current restoration efforts).
- Determine difference in future sediment delivery under No Action and Action scenarios.

11. REFERENCES

Asotin County Conservation District. 2004. Asotin Subbasin Plan – May 2004 Version. Prepared for the Northwest Power and Conservation Council. 179 pp plus appendices.

Bach, L. 1995. River basin assessment Upper/Middle Grande Ronde River and Catherine Creek. Oregon Department of Environmental Quality and Oregon Watershed Health Program.

Baker, S., F. Damian, J. Hall, and T. Beechie. 2005. Draft - Modeling erosion rates increases in the Interior Columbia River Basin. Draft Report. NMFS. 42 pages.

Boll, J., E. Brooks, and D. Traeumer. 2002. Hydrologic and Sediment Delivery Analysis of Agriculturally Dominated Watersheds in the Clearwater River Basin. Submitted by Dept. of Biological and Agricultural Engineering, University of Idaho to Idaho Soil Conservation Commission.

Bonneville Power Administration (BPA). 1997. Watershed Management Program Final Environmental Impact Statement DOE/EIS-0265. BPA. Portland Oregon.

Boucher, P. 1970. Sediment Transport by Streams in the Palouse River Basin, Washington and Idaho, July 1961 - June 1965. USDA Geological Survey Water=Supply Paper 1899-C. Washington, DC.

Bugosh, N. 2000. Lower Selway River Subbasin Assessment. Idaho Dept. of Environmental Quality (IDEQ). Lewiston, ID.

Bugosh, N. 1999. Lochsa River Subbasin Assessment. Idaho Dept. of Environmental Quality (IDEQ). Lewiston, ID.

Clark, K. 2003. Tributaries of the Palouse River Monitoring Report 2002 developed for Latah Soil and Water Conservation District, Idaho Soil Conservation Commission, Idaho State Dept. of Agriculture, and Idaho Dept. of Environmental Quality. Technical Results Summary KPC PR-02. Idaho Association of Soil Conservation Districts. Moscow, ID.

Clearwater BioStudies, Inc. 1993. Stream and Riparian Conditions in the Grande Ronde Basin. Final Report.

Clearwater River Focus Program. December 2005 (*Date accessed*). http://www.scc.state.id.us/clwfprogram.htm.

Columbia Conservation District. 2004. Tucannon Subbasin Plan prepared for Northwest Power and Conservation Council. Portland, OR. Available on-line: http://www.nwcouncil.org/fw/subbasinplanning/Tucannon/plan/.

Covert, J., J. Lyerla, and M. Ader. 1995. Initial Watershed Assessment Tucannon River. Washington Dept. of Ecology Open File Report 95-04. Olympia, WA.

Columbia River Intertribal Fish Commission (CRITFC). 1995. The Columbia River Anadromous Fish Restoration Plan of the Nez Perce, Umatilla, Warm Springs and Yakama Tribes. Wy-Kan-Ush-Mi Wa-Kish-Wit.

Columbia River Intertribal Fish Commission (CRITFC). 2002. FY2000 - FY2002 Pacific Coastal Salmon Recovery Fund Projects For The Columbia River Intertribal Fish Commission Tribes. Available on-line: http://www.critfc.org/text/pcsrf/pcsrf.html.

Diebel, K. 1997. Grande Ronde Basin Water Quality Monitoring, Plans for Six Key Watersheds. Union and Wallowa SWCD, Grande Ronde Model Watershed Program, La Grande, Oregon.

Ebbert, J., and R.D. Roe. 1998. Soil Erosion in the Palouse River Basin: Indications of Improvement. USGS Fact Sheet 069-98. USDA Natural Resources Conservation Service. Washington, DC. Available on-line: http://wa.water.usgs.gov/pubs/fs/fs069-

Ecovista, Nez Perce Tribe Wildlife Division, WSU Center for Environmental Education. 2003. Draft Clearwater Subbasin Assessment. Prepared for Nez Perce Tribe Watersheds Division and Idaho Soil Conservation Commission. Boise, ID.

Ecovista. 2003. Draft Clearwater Subbasin Inventory. Contracted by Nez Perce Tribe Watersheds Division. Lapwai, ID.

Ecovista. 2003. Draft Clearwater Subbasin Management Plan. Nez Perce Tribe Watersheds Division. Lapwai, ID.

Ecovista. 2004. Salmon Subbasin Management Plan. For Nez Perce Tribe and Shoshone-Bannock Tribe as part of Northwest Power and Conservation Council’s (NPCC) Columbia River Basin Fish and Wildlife Program.

Ecovista. 2004a. Imnaha Subbasin Assessment. Lead entity: Nez Perce Tribe. Planning Team:Wallowa Natural Resource Advisory Committee. Northwest Power and Conservation Council. Portland, OR.

Ecovista. 2004b. Snake Hells Canyon Subbasin Assessment. Lead entity: Nez Perce Tribe, prepared for Northwest Power and Conservation Council. Northwest Power and Conservation Council. Portland, OR.

Gilmore, S. 2004. Final Draft Palouse Subbasin Management Plan. Palouse Rock Lake Conservation District.

Grande Ronde Model Watershed Program. 2004. Grande Ronde Subbasin Plan. Prepared for the Northwest Power and Conservation Council. 494 p.

Green, W., W. Hashim, and D. Roberts. 2000. Washington's Water Quality Management Plan to Control Nonpoint Source Pollution. Washington Dept. of Ecology Publication 99-26. Olympia, WA.

Hecht, B., R. Enkehall, C. Ivor, and P. Baldwin. 1982. Sediment Transport, Water Quality, and Changing Bed Conditions, Tucannon River, Southeastern Washington. USDA Soil Conservation Service. Spokane, WA.

Hemstrom, M., T. Smith, D. Evans, C. Clifton, E. Crowe, and M. Aitken. 2002. Midscale analysis of streamside characteristics in the Upper Grande Ronde Subbasin, northeastern Oregon. USDA Forest Service Pacific Northwest Research Station Research Note PNW-RN-534. 16 pp.

Henderson, R. 2005. Palouse River Tributaries Subbasin Assessment and TMDL. IDEQ (Idaho Dept. of Environmental Quality). Lewiston ID. Available on-line.

Idaho Dept. of Environmental Quality (IDEQ). 1999. Lemhi River Watershed TMDL. Idaho Dept. of Environmental Quality. Boise, ID. December 1999.

Idaho Dept. of Environmental Quality (IDEQ). 2001a. Pahsimeroi River Assessment and TMDLs. Idaho Dept. of Environmental Quality. Boise, ID. December 2001.

Idaho Dept. of Environmental Quality (IDEQ) 2001b. Middle Salmon River-Panther Creek Subbasin Assessment and TMDLs. Idaho Dept. of Environmental Quality. Boise, ID. December 2001.

Idaho Dept. of Environmental Quality (IDEQ). 2002. South Fork Salmon River Subbasin Assessment. Idaho Dept. of Environmental Quality. Boise, ID. May 2002.

Idaho Dept. of Environmental Quality (IDEQ). 2003a. Addendum to the South Fork Salmon River Subbasin Assessment. Idaho Dept. of Environmental Quality. Boise, ID. July 2003.

Idaho Dept. of Environmental Quality (IDEQ). 2003b. Upper Salmon River Subbasin Assessment and TMDLs. Idaho Dept. of Environmental Quality. Boise, ID. January 2003.

Idaho Dept. of Environmental Quality (IDEQ). 2005. Draft Little Salmon River TMDL. Boise Regional Office. Boise, ID.

Idaho Dept. of Environmental Quality (IDEQ). 2001. Tammany Creek Sediment TMDL - Subbasin Assessment and Total Maximum Daily Load Analysis. 57 pages.

Idaho Dept. of Environmental Quality, Nez Perce Tribe and EPA. 2000a. Cottonwood Creek Total Maximum Daily Loads. IDEQ. Lewiston, ID.

Idaho Dept. of Environmental Quality, Nez Perce Tribe and EPA. 2000b. Jim Ford Creek Total Maximum Daily Loads. IDEQ. Lewiston, ID.

IAC (Idaho Administrative Code). 20.02.01 Rules Pertaining to the Idaho Forest Practices Act. Available on line: http://www2.state.id.us/adm/adminrules/rules/idapa20/0201.pdf.

Idaho Power Company (IPC). 2003. New License Application for Hells Canyon FERC Project No. 1971. Submitted to the Federal Energy Regulatory Commission. Application includes technical appendices. July 2003.

Idaho Soil Conservation Commission (ISCC). 1995. Model Watershed Plan; Lehmi, Pahsimeroi and East Fork Salmon River. U.S. Dept. of Energy, BPA. DOE/BP-2772. Portland, OR.

Idaho Soil Conservation Commission (ISCC). 2005a. Draft Cottonwood Creek Watershed Work Plan. Clearwater Focus Program, Subject to SRBA Court Protective Order- DO NOT RELEASE. Idaho Soil Conservation Commission. Boise, ID.

Idaho Soil Conservation Commission (ISCC). 2005b. Draft Lapwai Creek Watershed Work Plan. Clearwater Focus Program, Subject to SRBA Court Protective Order- DO NOT RELEASE. Idaho Soil Conservation Commission. Boise, ID.

Idaho Soil Conservation Commission (ISCC). 2005c. Draft Lawyer Creek Watershed Work Plan. Clearwater Focus Program, Subject to SRBA Court Protective Order- DO NOT RELEASE. Idaho Soil Conservation Commission. Boise, ID.

Jones, M., and H. Seitz. 1980. Sediment transport in the Snake and Clearwater Rivers in the vicinity of Lewiston, Idaho. USGS Water Resources Investigations Open File Report 80-690. Prepared in cooperation with the Corps, Walla Walla District.

Kaiser, V. 1975. Soil Erosion and Wheat Yields in Whitman County, Washington, Northwest Science, v.41, no. 2, p 86-91, 1967.

Kuttle, Jr., M. 2002. Salmonid Habitat Limiting Factors Water Resource Inventory Areas 33 (Lower) and 35 (Middle) Snake Watersheds, and Lower Six Miles of the Palouse River. 197 pages.

McCool, D., and R. Papendick. 1975. Variation of Suspended Sediment Load in the Palouse Region of the Northwest. Paper no. 75-2510. American Society of Agricultural Engineers. St. Joseph, MI.

McIntosh, B., J. Sedell, J. Smith, R. Wissmar, S. Clarke, G. Reeves, and L. Brown. 1994. Management History of Eastside Ecosystems: Changes in Fish Habitat Over 50 Years, 1935-1992. USDA Forest Service, Pacific Northwest Research Station General Technical Report PNW-GTR-321.

Middle Snake Watershed Planning Unit. 2005. Middle Snake River Watershed Level 1 Assessment - WRIA 35. Available on http://www.asotinpud.org/msww/.

Mobrand Biometrics. 1997. Application of the Ecosystem Diagnosis and Treatment (EDT) Method to the Grande Ronde Model Watershed Project.

Mobrand Biometrics, Inc. 2006. EDT Website. http://www.mobrand.com/MBI/edt.html.

Nelson and Burns. 2004. Deposition of Fine Sediment in the Salmon River Watershed, Boise and Payettte National Forests, Idaho. Statistical Summary of Interstitial and Surface Sediment Monitoring, 1983-2003. USDA Forest Service, Payette National Forest.

Northwest Power and Conservation Council (NPCC). 2004. Salmon Subbasin Assessment. NPCC. Portland, OR.

Oregon Department of Environmental Quality (ODEQ). 1997. Water Quality Report – Grande Ronde River.

Oregon Department of Environmental Quality (ODEQ). 1998. Oregon’s 1998 Section 303(d) List of Water Quality Limited Waterbodies, Oregon’s Criteria for Listing Water bodies and Basin Maps.

Oregon Department of Environmental Quality (ODEQ). 1998. Grande Ronde River Basin Water Quality Technical Assessment – Temperature.

Oregon Department of Environmental Quality (ODEQ). 1998. Grande Ronde River Basin Technical Assessment (Overview of Water Quality Conditions).

Oregon Department of Environmental Quality (ODEQ). 1999. Upper Grande Ronde River Sub-Basin Temperature Total Maximum Daily Load (TMDL).

Oregon Department of Environmental Quality (ODEQ). 2000. Upper Grande Ronde River Sub-Basin Total Maximum Daily Load (TMDL). April 2000.

Pettelier, G., D. Hallock, D. Serdar, R. Garrigues, and Hoyle-Dodson. 1995. Watershed Briefing Paper for the Upper and Lower Snake River Water Quality Management Areas. Washington Dept. of Ecology Publication 95-346. Olympia, WA.

Pomeroy Conservation District Landowner Steering Committee. 1998. Pataha Creek Model Watershed Plan. Pomeroy Conservation District. ID.

Pomeroy Conservation District. 2004. Lower Snake Mainstream Subbasin Plan. Northwest Power and Conservation Council. Portland, OR.

Quigley, T.M., and S.J. Arbelbide, Editors. 1997. An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins, Volumes I-IV. USDA Forest Service, Pacific Northwest Research Station and USDI Bureau of Land Management. General Technical Report PNW-GTR-405.

Radbruch-Hall, D.H., R.B. Colton, W.E. Davies, I. Lucchitta, B.A. Skipp, and D.J. Varnes. 1982. Landslide overview map of the conterminous United States. Geological Survey Professional Paper 1183. U.S. Government Printing Office, Washington, DC. 36 pp.

Reckendorf, F., and P. Pedone. 1989. Erosion and sediment impacts of the 1985 Food Security Act above Lower Granite Reservoir, Idaho, Oregon, and Washington. National Non-point Source Conference 1989, pages 199-136.

Reckendorf, F., P. Pedone, and D. Hoodenpyle. 1988. Erosion reduction impact of the Food Security Act above the Lower Granite Reservoir, Idaho, Oregon, and Washington. July 1988. 24 pages plus tables.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No. 703, U.S. Government Printing Office, Washington DC. 404 pp.

Resource Planning Ltd. 2003. Agricultural Pollution Abatement Program. For Idaho Dept. of Environmental Quality and Idaho Soil Conservation Commission. Boise, ID.

Shumar, M. 2002. Middle Salmon River-Chamberlain Creek Subbasin assessment and Crooked Creek Total Maximum Daily Load. Idaho Dept. of Environmental Quality (IDEQ). Boise, ID. December 2002.

Spangrude, G. 2004. Navigation Channel Maintenance, Snake and Clearwater Rivers Public Information Meeting In-River Sediment Transport. Available on-line: http://www.nww.usace.army.mil/dmmp/maintenance_dreding/presentation/gene/gne.htm.

Teasdale, G., and M. Barber. 2005. Aerial Assessment of Ephemeral Gully Erosion and Channel Erosion in the Lower Potlatch River Basin Research Report. State of Washington Research Center, University of Washington.

U.S. Army Corps of Engineers (Corps). 1975. Special Report: Lower Snake River Fish and Wildlife Compensation Plan, Lower Snake River, Washington and Idaho. Walla Walla District, Walla Walla, WA.

U.S. Army Corps of Engineers (Corps). 1991. Special Report: Lower Snake River Fish and Wildlife Compensation Plan. Wildlife Habitat Compensation Evaluation for the Lower Snake River Project. U.S. Army Corps of Engineers, Walla Walla District.

U.S. Army Corps of Engineers (Corps). 1996. Interim Report, Supplement to Special Report, Lower Snake River Fish and Wildlife Compensation Plan, Lower Snake River, Washington and Idaho. Walla Walla District, Walla Walla, WA.

USDA Cooperative State Research, Education, and Extension Services. 2004. Investigation of the changes in the Little Bear River Watershed in Response to the Implementation of Best Management Practices. Available at: http://cris.csrees.usda.gov/cgi-bin/starfinder/0?path=fastlink1.txt&id=anon&pass=&searsch=R=9766&format=WEBLINK.

USDA Forest Service (Forest Service) and USDI Bureau of Land Management (BLM). 1995. Decision Notice/Decision Record Finding of No Significant Impact for the Environmental Assessment for the Interim Strategies for Managing Anadromous Fish-producing Watersheds in Eastern Oregon, and Washington, Idaho, and Portions of California. (This document is also known as PACFISH.)

USDA Forest Service (Forest Service). 1995. Inland Native Fish Strategy Environmental Assessment Decision Notice and Finding of No Significant Impact. Intermountain, Pacific, and Northwest Regions. (This document is also known as INFISH.)

USDA Forest Service (Forest Service) and USDI Bureau of Land Management (BLM). 1997. An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins. Volume I. USDA Forest Service, Pacific Northwest Research Station General Technical Report PNW-GTR-405. Portland, OR.

USDA Forest Service (Forest Service) and Bureau of Land Management. 1995a. Decision Notice/Decision Record Finding of No Significant Impact for the Environmental Assessment for the Interim Strategies for Managing Anadromous Fish-producing Watersheds in Eastern Oregon, and Washington, Idaho, and Portions of California.

USDA Forest Service (Forest Service). Undated. Boise Adjudication Team summaries. Rocky Mountain Research Station, Boise Aquatic Sciences Lab, Boise Adjudication Team. On-line at http://www.fs.fed.us/rm/boise/teams/soils/Bat%20WWW/index.htm.

USDA Forest Service (Forest Service). 1995a. Inland Native Fish Strategy Environmental Assessment Decision Notice and Finding of No Significant Impact. Intermountain, Pacific and Northwest Regions.

USDA Forest Service (Forest Service). 1999. Watershed Analysis Catherine Creek – Ladd McAllister. Wallowa-Whitman National Forest, La Grande Ranger Station, La Grande, OR.

USDA Forest Service (Forest Service). 2003a. Record of Decision for the FEIS and Revised Land and Resource Management Plan. Boise National Forest. Boise, ID.

USDA Forest Service (Forest Service). 2003b. Record of Decision for the FEIS and Revised Land and Resource Management Plan. Boise National Forest. Boise, ID. July 2003.

USDA Forest Service (Forest Service) 2003c. Record of Decision for the FEIS and Revised Land and Resource Management Plan. Payette National Forest. McCall, ID. July 2003.

USDA Natural Resource Conservation Service (NRCS), USDA Forest Service (Forest Service), Union Soil and Water Conservation Service. 1997. Grande Ronde River Cooperative River Basin Study. Union County, OR.

USDA Natural Resource Conservation Service (NRCS). 2000. National Resources Inventory (Excessive Erosion on Cropland 1997, Acres of Highly Erodible Cropland 1997, Acres of Non-highly Erodible Cropland 1997). USDA NRCS Resource Assessment Division, Washington, DC. Available on-line: http://www.nrcs.usda.gov/technical/land/meta/m5083.html.

USDA Soil Conservation Service (SCS), Forest Service, Economics, Statistics, and Cooperatives Service. 1978. Palouse Cooperative River Basin Study. 182 pages.

USDA Soil Conservation Service (SCS), Forest Service, and Economic Research Service. 1984. Southeast Washington Cooperative River Basin Study. United States Department of Agriculture.

USDI Bureau of Land Management. (BLM) 1993. Biological evaluation, ESA Section 7 Consultation. Baker Resource Area, Vale District.

U.S. Environmental Protection Agency (EPA). 1980. An approach to water resources evaluation of non-point silvicultural sources: a procedural handbook. EPA-60018-80-012. Environmental Protection Agency, Washington, DC.

Upper Salmon Basin Watershed Project Technical Team (USBWPTT). 2005. The Screening and Habitat Improvement Prioritization for the Upper Salmon (SHIPUSS). Upper Salmon Basin Watershed Project. Salmon, ID.

Upper Salmon Basin Watershed Project. Website accessed 1/15/2006. http://www.modelwatershed.org/Projects.html.

Washington Dept. of Ecology. 2005. Transforming Watersheds Couse Creek - Asotin County. Ecology Publication 05-10-017. Olympia WA.

Washington Department of Ecology (WDOE). 2006. Website accessed January 2006. http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html#4.

Washington Dept. of Natural Resources (WDNR). 2002 Washington Forest Practices Rules. Available on line http://www.dnr.wa.gov/forestpractices/rules/.

Washington Department of Fish and Wildlife (WDFW). 2006. William T. Wooten Wildlife Area. Website accessed 1/20/2006. Available on line: http://wdfw.wa.gov/lands/r1woot.htm.

Washington State University (WSU). 2005. Quarterly Report Water Quality Monitoring February 2003 - February 2005. WSU Dept. of Biological Systems and Center for Environmental Education. Pullman, WA.

Appendix C: Upland Erosion Processes in Northern Idaho Forests (Draft Report)

Prepared by Elliot et al., 2010

Upland Erosion Processes in Northern Idaho Forests

William J. Elliot
Research Engineer

Randy B. Foltz
Research Engineer

Sue Miller
Hydrologist

Rocky Mountain Research Station, Moscow, ID

Draft, June 1, 2010

ABSTRACT

This is a synthesis of the sources of sediment in Northern Idaho forested watersheds. The greatest amounts of erosion are associated with infrequent wildfires. Sediment from these fires is gradually routed through the stream system, with the greatest amounts of sediment transport associated with infrequent periods of stream flows. The forest road network is the second greatest source of sediment, generating sediment annually. At times this sediment may accumulate in channels until higher flow rates flush it downstream. Landslides and debris flows can contribute significant amounts of sediment during infrequent wet years, or following wildfire. A relatively new source of sediment in forested watersheds is from recreation, particularly all-terrain vehicle trails. The amounts of sediment from these sources has yet to be quantified. Lesser amounts of sediment can be attributed to mining operations, particularly those that were abandoned decades past. Stream channels store and route sediment, but in the absence of channel disturbance, tend to reach an equilibrium condition where sediment entering a given reach is balanced by sediment carried on downstream. If watershed managers wish to reduce sediment generated from upland areas in Northern Idaho forests, the most useful steps that can be taken are to stabilize or remove roads, and to carry out forest management activities to minimize the risk of a high severity wildfire. Both of these practices are common on federally-managed forests to the extent that resources have been made available. Additional sediment reduction may be possible on areas that have been significantly disturbed by mining and still have not recovered.

KEY WORDS

Soil erosion, landslides, disturbed forests, forest roads, watershed health , water quality

INTRODUCTION

Scientists have been studying erosion processes in Northern Idaho forests for nearly a century. A considerable number of papers have been written on the subject. The purpose of this synthesis is to summarize the key processes that lead to upland soil erosion and/or the delivery of sediment to streams. The area of consideration includes the Lower Snake and Salmon, Clearwater, Coeur d'Alene and Ponderay River Basins. The same principles and processes are applicable to forested watersheds throughout the world.

PHYSICAL SETTING

The descriptions of the geologic setting and the Landform setting are from McClelland et al., 1997, a report on the 1995-96 landslides in the Clearwater Basin.

Geologic Setting

There are five geologic parent materials in Northern Idaho: Batholith, border, belt, basalt and alluvium. The Idaho Batholith consists primarily of granitics (Figure 1). Granitics are coarse textured igneous intrusive rocks that today are commonly deeply weathered and have resulted in grussic (loose singe grain) soils. Exposed surface soils derived from these materials tend to be subject to severe surface and landslide erosion.

Belt series materials are weakly metamorphosed rocks which typically consist of clean quartzite, argillites, siltites and carbonates. Soils derived from these materials usually contain large percentages of angular coarse fragments which increase shear strength. They tend to be less erodible than the granitics.

Columbia River basalts are layered volcanic materials which today vary from hard weakly weathered rocks to extensively weathered rocks. Resulting soils are fine textured and cohesive, making them less erodible than the granitics, but more likely to generate runoff.

Materials resulting from surface erosion and deposition over geologic time are termed alluvium. Alluvium is found in all recent stream terraces adjacent to major streams, old terraces and bottomlands. These lands have old, well developed, silty to gravelly soils and commonly have high water tables and fragipans. The soils tend to be more erodible, although they frequently are less steep than the highly erodible granitics. Stream channel erosion is more pervasive on these materials.

Climates

The climates in Northern Idaho have wet winters and dry summers. Figure 2 shows the distributions of precipitation and temperature for Elk River and McCall, ID (DRI, 2009). As elevation and latitude increase, precipitation amount increases (Figure 3) and temperatures decrease. Thus areas with higher precipitation have a greater fraction of that precipitation as snow.

Soils

The soils in Northern Idaho are a reflection of the underlying geology, ranging from fine textured cohesive soils derived from basalts to coarse textured sandy and gravelly soils typical of the Batholith. In many areas, particularly in the Northern Basins, these soils are overlain by volcanic ash. The main source of this ash was from the Mt. Mazama eruption that formed Crater Lake in Oregon. Depths of 150 to 200 mm were estimated in Eastern Washington, with the depth decreasing further east into Idaho (Kimsey et al., 2007). These soils can form fragipans, increasing runoff amounts and erosion, and are more susceptible to compaction associated with forest management activities. Generally, the more shallow the ash layer, the less severe the risk of erosion and compaction.

The Lower Salmon Basin is dominated by coarse-grained granitic soils derived from the Idaho Batholith (Megahan and King, 2004). These soils tend to have relatively high hydraulic conductivity values leading to low runoff rates unless disturbed by forest access or fire. They are less susceptible to compaction than the ash cap soils.

SOURCES OF SEDIMENT

Water borne sediment in Northern Idaho is generated by three main processes; surface erosion, mass wasting, and stream channel erosion. The three processes can often overlap or complement each other. For example, following a wildfire, surface erosion may exceed the ability of a channel to transport the eroded sediments, so sediment accumulates in flood plains. In the decades that follow, deposited sediments are gradually entrained and transported further downstream. A landslide may expose bare mineral soil, aggravating surface erosion. Stream bank erosion may undercut a steep bank at the toe of a marginally stable hill, resulting in a landslide (Reid, 2010).

Surface erosion is generally minimal unless a hill slope is disturbed (Megahan and King, 2004, Elliot, 2010). The two main disturbances are wildfire and the road network. Other disturbances are associated with timber harvest, prescribed fire, recreation access, and animal activity. Mining can also generate sediment if not properly managed (Wireman, 2000). Superimposed on these surface disturbances are climatic factors that lead to major runoff events, like heavy rainfall, rapid warming resulting in high snow melt rates, or heavy rain falling on a snow pack ("rain-on-snow"). Weather events that result in most of the erosion only occur about 1 year in ten. Times when a disturbance is followed by severe weather are when the greatest erosion occurs (Megahan and King, 2004, Elliot, 2010). Recent studies over several decades have suggested that in Idaho batholiths, sediment yields range from 5 to 25 ton/sq mile/yr, whereas cosmogenic studies of the same area indicate that true long term (thousands of years) erosion rates are likely to be 250 to 1200 tons/sq mile/yr (Kirchner et al., 2001)

Surface erosion by water results from the interactions of a number of different but related processes. The three dominant processes are soil detachment, sediment transport, and sediment deposition. Soil is detached by raindrop impact, by shallow overland, or by concentrated flow in rills or road ruts or ditches. The transport capacity of flow is a function of sediment particle density and diameter, flow rate and channel steepness. Runoff can be generated by precipitation and/or snowmelt rates in excess of the soil infiltration capacity. The infiltration capacity depends on soil properties, residue on the soil surface, vegetative canopy and soil water content (Elliot, 2010).

Additional processes are associated with sediment detachment and delivery that are dependent on surface conditions. Within forested watersheds, surface erosion can be subdivided into either erosion from disturbed forest hillslopes, or erosion associated with forest access (roads and trails) (Megahan and King, 2004). Hillslopes can be viewed as polygons on the landscape while access corridors tend to be viewed as linear features.

SURFACE EROSION

In forests, surface erosion is generally found on disturbed forested hillslopes and on the forest road networks. Roads and other forest access tend to erode every year that they are used, and are considered a chronic source of sediment, whereas forested hillslopes generally experience erosion in the year or years following a disturbance.

Disturbed Forested Hillslopes

Undisturbed forest hillslopes have zero, or very little surface erosion. Disturbances from animals (Elliot and Miller, 2004; Reid, 2009), upturned tree roots (Reid, 2009) or other natural disturbances can sometimes generate small amounts of sediment. Elliot and Miller (2004) measured erosion rates of 220 kg/ha associated with animal activity compared to less than 1 kg/ha in the absence of animals. The greatest natural disturbance is wildfire. Human disturbances like logging, thinning, and other fuel reduction activities can also generate sediment, leading to erosion rates of 1 Mg/ha or less.

Wildfire

Idaho forest ecosystems are fire adapted (Baily, 2009), with plant communities that are able to thrive in spite of wildfires with frequencies varying from 50 to 300 years (Agee and Skinner, 2005; MacDonald et al., 2000). The greatest surface erosion rates in forested watersheds usually follow wildfire (Figure 4). Erosion rates following wildfire is dependent on the weather the following year (Megahan and King, 2004, Robichaud et al., 2007), and typically range from 1 to 20 Mg/ha.

Following wildfire, forest managers frequently evaluate the potential for soil erosion, and if justified because of values at risk downstream, may initiate actions to reduce the risk of runoff and erosion (Robichaud et al. 2000). Common treatments include mulching burned hillsides and storm-proofing of roads. Research has shown that these practices are effective for smaller events, but may be of limited use should there be a larger runoff event within two or three years of a severe wildfire (Robichaud, 2005)

Forest Management

In the last half of the twentieth century, timber harvest was the dominant forest management practice to provide building materials for the post world war II building boom (Megahan and King, 2004). In addition to timber harvest, a proactive fire suppression strategy was followed. These two practices have resulted in forests with an overabundance of even age timber with a considerable amount of understory. This type of stand is highly susceptible to wildfire, and the frequency and severity of wildfire has been increasing in recent decades (Agee and Skinner, 2005).

In the past decade, management of federal forests has focused on fuel management to reduce the risk of high severity wildfire (Agee and Skinner, 2005). State and privately owned forests, and some federal forests still continue to harvest timber for sale, but in all cases, much greater consideration is given to forest and watershed health (Karwan et al., 2007, Reinhardt et al., 2008). These activities are often referred to as “Fuel Management” (Elliot et al., 2010). The most common fuel management practices are thinning, particularly to remove the understory (Figure 5), and the use of prescribed fire (Figure 6). Erosion from thinning will be similar to the undisturbed forest, whereas erosion from the prescribed fire is typically increased by a factor of 10 in the year following the treatment. As forest erosion is dominated by a few large runoff events in a century, the risk of a high erosion rate is low, but severe if such an event does occur. Fuel management activities can cost between $500 and $1000 per acre. Sometimes the costs are partially or totally born by the sale of merchantable timber. Recent studies have shown that these practices do not necessarily reduce the likelihood of a wildfire occurring, but they tend to reduce the severity of the fire (Reinhardt et al., 2006). A reduction in fire severity will likely lead to a significant reduction in erosion, depending on the weather in the years following the fire (Robichaud, 2005).

In recent years, interest in using forests as a source of biomass for fuels has increased (Rummer et al., 2000). They reported that erosion rates predicted for fuel management ranged from 0 to 1 ton/acre, depending on climate and topography. The analysis included consideration of increased road erosion as well as erosion from the harvested areas (Elliot and Miller, 2002).

Even though the increase in erosion on forested hillslopes due to timber harvest, fuel reduction or biomass removal will likely be minimal, the increased use of roads and skid trails as described below can increase overall sediment yields (Robichaud et al., 2010). Foltz et al. (2009) observed that roads become overgrown if not used, but should that road be cleared and used for logging traffic, the erosion rates would increase by a factor of 100.

Forest Access

Forests in Northern Idaho serve a multitude of uses including fiber production, grazing, and recreation. All of these uses require some form of access, as do fire suppression activities. Access is via federal, state, county and private roads. These access networks are further extended with temporary or long term trails that can be made by logging skidders, all-terrain vehicles (ATVs), bicycles, wild and domestic animals and humans. In the absence of wildfire, it is these access corridors that are generally recognized as the greatest generator of sediment within our forests (Megahan and King, 2004).

Forest Roads

Forest roads have long been identified as a significant source of sediment in forested watersheds (Megahan and King, 2004). Road erosion rates range from less than 1 to 10 Mg/ha, compared to forests with erosion rates of only a few kilograms per hectare. Sediment delivery from roads depends on the road surface conditions, road location, topography, soil properties, design, use, and management. Roads can be insloped, outsloped, or crowned – a combination of insloped and outsloped (Figure 7). If the roads are not well-maintained, they soon become rutted from traffic.

Newly-constructed or reconstructed roads generate much more sediment than older roads (Burroughs and King, 1989, Megahan and King, 2004). Even older roads will tend to generate some sediment unless they become fully vegetated, including all fill slopes and cut slopes (Foltz et al., 2009; Megahan and King, 2004; Figure 7). Older roads are also a perpetual risk of significant sediment generation from blocked culverts (Elliot et al., 1994; Guckinski at al., 2004).

The road running surface has a much lower hydraulic conductivity than the surrounding forest, with measured values from less than 1 mm/h to about 10 mm/h. In contrast, the hydraulic conductivity of the surrounding forest ranges from 20 to more than 100 mm/h. The net result of these differences is that the road is generally a source of surface runoff and erosion, whereas the forest is an area where the road runoff infiltrates back into the soil and deposits sediment that was entrained from the road surface (Figure 8). Shorter road segments generating runoff, and larger buffers between roads and streams result in less delivery of eroded sediment. One common "best management practice" (BMP) is to shorten the length of the road segment that generates the runoff by installing a cross drain (Elliot et al., 1999a). A cross drain can be a road surface runoff diversion, like a water bar, a broad base dip or an open top culvert; or a ditch relief culvert on an insloped road.

Road erosion can also be minimized by preventing rut formation (Figure 9) and diverting runoff either directly to the fill slope with an outlsoped road, or to an inside ditch with a insloped road, if the inside ditch is non erodible. Ditches that are vegetated, or have been armored with gravel, another BMP, have minimal erosion, whereas a bare ditch in a newly constructed road could generate considerable sediment (Luce and Black, 1999). Within the highly erodible batholith soils in the Salmon Basin, ditch erosion can be considerable. It is less of a problem in the more stable Belt Series soils in much of the Clearwater Basin (Figure 1).

Road rutting can be minimized several ways. The most common methods are either through regular grading, or with the addition of gravel. Reduced income from timber sales in the last 20 years have resulted in reduced maintenance of roads, leading to a backlog of road maintenance needs on federal lands. This reduced maintenance has led to increased road surface erosion in forested watersheds (Gucinski et al., 2001).

Gravel increases the ability of the road to carry traffic without rut formation. The gravel itself can be a source of fine sediment, however. Research has shown that the content of fine sediment (less than 200 mm diameter) is the best indicator of the likelihood that the gravel will be a source of sediment (Foltz and Truebe, 2003). Gravel with few fines, however, is not desirable because it is more likely to roll off the road surface with no fines to bind it together. Thus road managers must compromise on gravel size to ensure the fines content is adequate to stabilize the road surface.

Another method for minimizing rut formation and subsequently road erosion is to reduce the pressure in the tires of vehicles operating on the roads, particularly logging trucks or other heavy vehicles (Foltz, 1994). Figure 9 shows ruts forming in the Foltz (1994) study on the treatment with high tire pressure. The lower pressure treatments did not have discernable ruts when this photo was taken. The technology to reduce tire pressures on forest roads, but increase pressure for highway operation is well established, but is generally too expensive for most truck fleet operators to consider, although this approach was considered for a recent timber sale in the Salmon Basin.

In many cases, it is possible to minimize rutting by seasonally closing roads. As many roads are closed for the winter, extending that closing season to include a few weeks either side of the winter when road surfaces are wet can significantly reduce rut formation. Closure is not always popular with the public, as these periods often include the fall hunting season and early spring fishing and mushroom collecting seasons. For most road networks, a combination of the above management practices is required to minimize sediment generation.

Another factor that influences road erosion is traffic. Roads with heavy traffic generate 4 to 5 times the sediment of roads with low traffic (Foltz, 1996; Luce and Black, 1999; Robichaud et al., 2010). Heavy traffic can generate fine sediment through crushing gravel or causing more erodible subgrade material on the road to squeeze through pores in the aggregate until it reaches the surface where it can be eroded. The most common BMP to offset the effects of heavy traffic is the application of gravel, preferable enough to ensure that subgrade material does not reach the surface. It may also be possible to restrict heavy traffic to the drier times of the year, when precipitation is minimal, or to the winter when the road is frozen.

Once the sediment leaves the road, the buffer can be a source of sediment. Outsloped roads seldom generate any sediment in the buffer, although there may be some evidence of erosion on the fill slope (Figure 7). On rutted and inslope roads, however, sediment collected in the ruts and/or the inside ditch can be transported down the slope in a channel if the cross drain delivers the runoff to a swale or ditch. In these cases, there is a risk for offsite erosion that may generate more sediment than was generated from the road itself (Elliot and Tysdal, 1999b). Ketcheson and Megahan (1996) noted that the amount of surface debris on the buffer influenced sediment deposition and delivery. Results from a study on the BMP of windrowing slash along the base of the cut slope showed that the windrow has the potential to absorb all of the road runoff, thereby eliminating any down slope transport of road sediment (Figure 10; Foltz and Elliot, 2001; Robichaud et al., 2010)

Because of the sediment problems associated with roads in watersheds, there has been a considerable effort to remove roads in Northern Idaho (Figure 11). Removing, obliterating, or recontouring roads is widespread throughout these basins. Research has shown that a minimal amount of sediment is generated during these operations (Foltz et al., 2008). This is an expensive operation, costing up to $6000 per kilometer of road removed. In some cases, it may be possible to minimize the sedimentation risk from roads by removing culverts and outsloping the remaining road segments. Such a practice means that should it be necessary, the road can be made usable without requiring a completely new construction.

Skid Trails

Logs are generally collected from forests with tracked or rubber-tired skidders (Figures 12 and 13) on slopes less than about 25 percent, and with overhead cables on steeper slopes (Figure 14). In sensitive areas, logs can be abstracted with a helicopter, but its cost may be prohibitive.

Skid trails are used transport logs from where they have been cut to a landing alongside a road, where they may be processed before loading onto trucks for transport to the mills. Erosion rates of skid trails are dependent on how many passes of the skidder they have experienced, and, like roads, where they are located on the landscape. Generally, the more mineral soil is exposed in skid trails, the greater the erosion risk. Generally, even high traffic skid trails retain around 80 percent cover, unless the operator has dropped the blade on the skidder to level the trail. With high cover, erosion is minimal. Bare skid trails, however, can be highly erodible (Wagenbrenner et al., 2010). Common BMPs to minimize skid trail erosion are to mulch the trail once a logging operation is complete with slash and to install water bars, generally about every 50 ft. The further a skid trail is from concentrated flow, the less likely it is to delivery sediment to the stream system. In the northern Idaho, restricting skid trails within about 30 ft of flowing water is generally adequate, especially if mulching and water bars have been installed. Other BMPs to minimize skid trail erosion are to limit access during those times of the year when soils are wet, and carrying out most operations on dry, frozen, or snow covered soils, and minimizing the area of a watershed that is in skid trails. A general guideline is that no more than 15 percent of the watershed should be disturbed by skid trails, but the distribution of that disturbance can be as important as the amount, as trails nearer the ridge tops generate much less sediment than trails near streams. Cable operations tend to cause fewer disturbances than skidders, although the steepness of the cable corridor is usually greater than on ground-based skidders.

Another machine to transport logs from a forest to the landing is a forwarder (Figure 15). A forward carries rather than drags the logs, and often operates at higher ground speeds. Higher speeds mean that it may be possible to transport logs further with a forwarder than a skidder, reducing the density of the required road network. Like ground-based skidders, operations are limited to slopes less than about 20 percent. Forwarders are very heavy machines with a fully loaded forwarder weighing more than 20 tons. These heavy machines can cause considerable compaction or rutting if used when soils are wet, leading to a risk of increased runoff and erosion in subsequent seasons. Many operations using forwarders will run the forwarder on a mat of slash, protecting the soil underneath, and leaving little soil exposed so that subsequent erosion is generally minimal, even though runoff may be increased because of the compaction (Elliot, 2010).

Recreation

One of the growing uses of forested areas is for recreation. Recreation impacts include camp grounds, increased traffic on forest roads, erosion associated with All Terrain Vehicles (ATVs; Figure 16), and other trails. Since camp grounds are generally on flat areas and tend to be grassy, most erosion is limited to roads or parking areas. If heavy use causes a loss of ground cover, then there may be a risk of delivering sediment to the stream. The effect of increased traffic on road erosion was discussed previously. Erosion from human or animal trails is likely to be limited as trails are small, but could be significant where steep trails segments cross streams. In such cases, BMPs such as water bars and gravel as discussed for roads would minimize sediment generation and delivery.

ATV trails are a growing risk for sediment generation in forests. Research has shown that the erosion risk from ATV trails may exceed that of any other disturbance in a forest. Current practices of designating trails some distance from streams will minimize this source of sediment, but it may take a few years to train ATV users on the importance to watershed health of staying on designated trails. Other practices similar to those recommended for roads and skid trails are frequently recommended to minimize this source of sediment (Meadows et al., 2009).

MASS EROSION

Three types of mass erosion: shallow landslides, debris flows, and deep-seated landslides, predominate in northern Idaho forests. Shallow landslides have a variety of definitions. One is any slide that involves only colluvial material. Another is that the depth to the failure plane is markedly less than the length or width of the slide. Debris flows refer to slides that displace saturated material and flow downslope as a mass of fluid, soil, and vegetation, generally following an ephemeral channel or swale in the landscape. Deep-seated landslides have failure surfaces within bedrock or are slides that are deep relative to their length.

Shallow landslides most often occur when high-intensity, long duration rain events fall on deep snowpacks. These events saturate the soil and reduce the magnitude of the forces holding soil on the hill side. When the forces holding soil on the hill side are less than the forces moving the soil downhill, a shallow landslide will occur. Slide occurrences are also influenced by hillslope gradient, root cohesion, soil water content, lateral slope convergence, bedrock type, soil depth, and soil texture (Hammond et al., 1992). Most shallow landslides contain a wide range of grain sizes as well as woody debris. Shallow landslides are the most common type of landslides within the Belt land types whereas debris flows are more widespread in the Batholith (Figure 1). Shallow landslides are often associated with road cut slopes and fill slopes (Figure 17)

Debris flows are characterized by soil movements that contain such large amounts water that they flow as a fluid. Stream channels often serve as sources for this type of landslide. Debris flows are often high density with over 80 percent solids by mass, may exceed the density of wet concrete, and often move boulders up to 1 m in diameter (Figure 18). Soils on steep slopes unprotected by vegetation, common after wildfires, are prone to debris flows (Megahan and King, 2004). Debris flows are more common in the Batholith land type of the Salmon Basin.

Deep-seated landslides have failure surfaces in bedrock or are deep relative to their length. This type of landslide is more responsive to seasonal rainfall than are the shallow landslides. Also unlike shallow landslides which do not continue to move, deep-seated landslides can remain active for decades or longer. Sediment in deep-seated landslides ranges from clays to large blocks of bedrock. Volumes from deep-seated landslides tend to be quite large and often are a major fraction of the total volume from large areal extent landslide events (Kirchner et al., 2001; McClelland et al., 1997).

Landslide risks in northern Idaho forests are considerably less than in other portions of the Pacific Northwest such as the Coast Ranges of Oregon, Washington, and California. Burroughs (1985) concluded that about 10 percent of the national forest lands in northern Idaho, and 12 percent of the national forest lands in southern Idaho have a “high potential” for landslide occurrence.

Large water inputs to the soil surface trigger both landslides and floods. In the Pacific Northwest the largest water inputs come from rainfall, snowmelt, or a combination of rainfall and snowmelt known as rain-on-snow. Widespread landslides are usually caused by rain-on-snow events that have a return period of 15 to 20 years. Major flood events in the Clearwater River drainage have occurred in 1919, 1933, 1948, 1964, 1968, 1974, and 1995/96 which is a major flood event approximately every 13 years (McClelland et al., 1997).

In 1933 the largest flow event ever occurred on the St. Joe River and the third largest on the North Fork Clearwater, the Clearwater, and the Lochsa River. A review of 1935 aerial photos suggests that there were major landslide events associated with the peak flows of 1933. The largest event ever on the Selway and Lochsa Rivers occurred in 1948. Anecdotal reports suggest major landslide events were associated with the flood event. In 1964 the second largest event occurred on the Lochsa and the third largest on the Selway Rivers. This high flow event did not result in any landside report specific to the Clearwater National Forest. In 1974 the largest flow event ever occurred on the Coeur d'Alene River and the second largest on the St. Maries and the Palouse Rivers. There were a significant number of landslides associated with this flood.

The winter 1995-96 experienced two distinct high flow and landslide periods. A November 1995 rain-on-snow event resulted in 10 to 25-year events on larger streams with the Palouse River at Potlatch, ID experiencing the highest flow in 35 years of record. In February 1996 another rain-on-snow event occurred with widespread flooding and 50 to 100-year flow events on many of the rivers and streams below 4,000 feet elevation in the Clearwater River basin. A large number of landslides resulted from these two rain-on-snow events.

The 1974 and the 1995/96 landslide events were documented by Megahan, et al. (1978) and by McClelland, et al. (1997), respectively. The snowpack and subsequent rain-on-snow events were similar for both years. During December 1973 and early January 1974, the Clearwater Mountains experienced heavy snowfalls with high water content. In mid-January, sudden warm temperatures in combination with a rain-on-snow storm accounted for 280 mm of snowmelt and approximately 75 mm of rainfall within 5 days. The rainfall for November-December 1995 and February 1996 averaged 147 and 114 mm, respectively. McClelland, et. al estimated that about 250 mm of snowmelt occurred during the February 1996 storm, implying that the total precipitation plus snowmelt were the same for both the January 1974 and the February 1996 storms. Both studies suggest that a snowpack of 150% to 200% of normal followed by rainfall of 100 to 125 mm in a five day period will result in a high probability of major landslide events in the Clearwater basin.

McClelland et al. observed that 1200 to 1600 m was the dividing line between rain-on-snow and snow-on-snow events. Above this elevation there were significantly fewer landslides with river return periods near 2 year intervals. For the 1995/96 events there was a drop in landslide rate of greater than 1 landslides per 800 ha for elevations below 1600 m to 1 landslide per 4000 ha for elevations greater than 5,000 feet. Elevation relationships associated with landslides can also be correlated with several landscape characteristics. A rather abrupt change in soil and landform processes and resultant landforms also occurs at this elevation. Soil forming processes associated with chemical weathering below 1600 m elevation rapidly change to processes associated with physical weathering and frost churning above 1600 m elevation. Subalpine vegetative habitat types also start appearing near 1600 m. This suggests that these patterns are well established and long term thus rendering some portions of the landscape more susceptible to landslides than others.

Geologic parent material was an important indicator of landslide susceptibly. Border and Batholith material accounted for 80 to 84 percent of the landslides in both the 1978 Megahan and the 1995/96 McClelland study (Figure 1).

In the 1995/96 landslide event there were 900 landslides with an estimated volume of 20 cubic meters or greater on the non-wilderness portion of the Clearwater National Forest. McClelland et al. estimated a total volume displaced of 530,000 cubic meters of which 300,000 cubic meters (57% of displaced volume) was delivered to streams. Two landslides, No-see-um Creek and Quartz Creek, accounted for 230,000 cubic meters of the 530,000 cubic meters displaced from large deep-seated landslides. Their assessment attributed 71% of the delivered volume to natural causes, 25% attributed to roads, and 4% to harvest areas.

Wilson et al. (1982) reported an average annual sediment yield of 8.7 Mg/sq km/year for undisturbed drainages on the Clearwater National Forest. The natural sediment yields were generated by in-channel erosion of banks and beds. Wilson et al. distributed the natural sediment loading as follows: 20 percent due to erosion primarily from areas denuded by historic fire cycles and the remaining 80 percent to natural landslides. The bed and bank material was supplied principally by long-term mass movement and, to a lesser degree, by natural surface erosion from areas denuded by catastrophic wildfires. McClelland et al. (1997) reported that Gerhardt, a retired Nez Perce National Forest hydrologist, obtained an average annual sediment yield of 9.4 Mg/sq km/year for the Selway River drainage near its confluence with the Lochsa River. The Selway River drainage has little timber harvest and few roads above the sampling location so that these results should approximate the natural background rate. No substantial landslide occurred during the five year sampling period of 1988-1992. Based on these two studies, McClelland et al. (1997) estimated the total sediment delivered from the 1995-96 events generated approximately 10 times the natural background landslide sediment.

Forest Roads

Roads on steep slopes are often source areas for landslides. Construction of the road into the hillside results in both the cut slope and the fill slope being steeper than the surrounding hillside (Figure 17). In the two recent landslide events (1974 and 1995/96) roads were the source area for 58% of the landslides on the Clearwater National Forest. Cut slope failures were predominate in the 1974 event (66% of road landslides) while fill slope failures were predominate in 1995/96 (75% of road landslides). In the 1995/96 event, thirty-five percent of the total estimated landslide volume was from roads with 25% of the total estimated volume delivered to streams was from roads. Many of the 1995/96 road related landslides originated from old, low use, unmaintained secondary forest roads where plugged culverts lead to fill slope failures (Figure 18; Elliot et al., 1994). Since 1997, unstable roads such as those in Figure 17 have been prioritized for obliteration by the Forest Service in an effort to reduce landslide risks and subsequent adverse impacts on water quality.

CHANNEL EROSION AND SEDIMENT DELIVERY

This section focuses on the generation of sediment from first or second order stream channels. These channels tend to be more dynamic as they receive, route, store, and re entrain sediment generated by disturbed hillslopes and roads. Sediment detachment processes are frequently divided into channel bed scour, channel bank scour, and bank mass erosion.

Channel bed erosion is generally a function of the size of material on the bed and the ability of the stream flow to entrain that material. In the absence of disturbance, upland beds tend to be coarse. Roads, wildfire and upstream erosion can generate fine sediment in excess of the sediment transport capability of some stream segments, and the bed can become covered with fines (Elliot, 2006; Hairsine and Rose, 1992). These fines tend to accumulate during low runoff events, but can be flushed downstream during bank full flows, which occur about once every two years. During even larger events, the material may be mobilized and deposited on adjacent flood plains.

Stream bank erosion is also driven by larger flow events. Bank erosion is frequently much greater from mass failure when the toe of a bank is undercut by channel erosion, followed by a period of high flow which can saturate the bank, and then a drop in flow, leaving the bank weakened by saturation and unstable from undercutting (Reid, 2010). The bank will then topple into the stream, and gradually the blocks will be eroded and transported downstream by the stream flow (Figure 19).

Stream banks can also be weakened when vegetation on the bank is removed by grazing or fire. Current management practices seldom allow timber removal from banks. The loss of vegetation will reduce the bank's stability as the roots that may have been stabilizing the soil gradually die and decompose (Buckhouse, 2000).

Many streams in northern Idaho have been disturbed by mining. In some streams, dredging of bed material has altered the channel substrate. Gravel, metal, and gem mining has been common in many alluvial deposits. In other areas, surface or shaft mining has generated large spoil piles that have been built in flood plains after rerouting the streams. In all of these cases, as a stream recovers from these in stream or stream side disturbances, additional sediment could be generated until the stream channel reaches a state of equilibrium (Reid, 2010). This process occurs over decades, with major steps in channel reforming associated with larger flow events. Mine recovery is complicated by challenges in soil remediation and vegetation establishment, which are beyond the scope of this report.

Downstream straightening of channels can aggravate stream stability, leading to head cuts or increased meandering and bank erosion. The bank erosion in Figure 19 is a result of downstream channel alteration about 20 years earlier to accommodate an airport. These processes can continue for decades contributing to stream sediment generation. Attempts to stop meandering are expensive and may or may not work. In some cases, when a stream is not in equilibrium with its surroundings, watershed managers may resort to reestablishing meanders (Fangmeier et al, 2006). In other cases, it may be possible to stabilize the bank with carefully placed woody debris and appropriate vegetation.

There are also natural channel disturbances. The two most common are wildfires, increasing the risk of both surface sediment delivery and mass erosion, and landslides occasionally introducing large point sources of significant amounts of sediment to be stored and/or routed by the channel.

When channels or banks are not disturbed, channels will reach an equilibrium condition (Reid, 2010). This process may take years following many of the above disturbances. Until it reaches equilibrium, it will tend to be a source of additional sediment.

SUMMARY

This report has given an overview of erosion processes in Northern Idaho forests. The greatest amounts of erosion are associated with infrequent wildfires. Sediment from these fires is gradually routed through the stream system, with the greatest amounts of sediment transport associated with infrequent periods of stream flows. The forest road network is the second greatest source of sediment, generating sediment annually. Recreation may be an increasing source of sediment in forest watersheds, but managers are developing practices to minimize this source of sediment. At times eroded sediment may accumulate in channels until higher flow rates flush it downstream. Landslides and debris flows can contribute significant amounts of sediment during infrequent wet years, or following wildfire. Stream channels store and route sediment, but in the absence of channel disturbance, tend to reach an equilibrium condition where sediment entering a given reach is balanced by sediment carried on downstream.

If watershed managers wish to reduce sediment generated from upland areas in Northern Idaho forests, the most useful steps that can be taken are to stabilize or remove roads, and to carry out forest management activities to minimize the risk of a high severity wildfire. Both of these practices are common on federally-managed forests to the extent that resources have been made available. Additional sediment reduction may be possible on areas that have been significantly disturbed by mining and still have not recovered.

Areas for Further Work

One area that would benefit from additional research is to increase our understanding of sediment processes between the road and the stream. Information is scarce on the fate of detached sediment leaving roads, and the conditions that can cause erosion in road buffer areas.

Most forest managers know that with modern logging equipment, fewer roads are needed. Methods need to be developed to determine the optimal road network for a given forest plan. Another area in need of research on optimizing road networks to meet management need. With treatments to reduce the risk of wildfire, it may be possible to target such treatments to protect watershed health by diverting wildfire away from sensitive areas with a watershed, as well as other values of risk.

Scientifically sound management practices of ATV trails need to be developed, installed, and articulated to the public. Further work quantifying sedimentation from ATV trails and reduction of sediment associated with BMPs needs to be developed to help justify improved trail management.

REFERENCES

Agee JK, Skinner CN (2005) Basic principles of forest fuel reduction treatments. *Forest Ecology and Management* **211**, 83-96.

Baily, R.G. 2009. Fire regimes and ecoregions. IN. Elliot, W.J.; Miller, I.S.; and Audin, L. (eds.). *Cumulative Watershed Effects of Fuel Management in the Western United States*. Gen. Tech. Rep. GTR-231. Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station. 7-18.

Buckhouse, J.C. 2000. Domestic grazing. IN Dissmeyer, ed. Drinking Water from Forests and Grasslands A Synthesis of the Scientific Literature. General Technical Report SRS-39. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 153-157.

Burroughs, E. R., Jr.; King, J. G. 1989. Reduction of soil erosion on forest roads. USDA Forest Service Gen. Tech. Rep. INT-264. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 pp.

Desert Research Institute (DRI). 2009. Western Regional Climate Center. [Online]. Available: www.wrcc.dri.edu/index.html [October 20, 2009].

Elliot, W.J. 2006. The roles of natural and human disturbances in forest soil erosion. Chapter 17. In Owens, P. N. and A. J. Collins (eds.). *Soil Erosion and Sediment Redistribution in River Catchments*. Wallingford OX, UK: CAB International. 177-185.

Elliot, W.J. 2010. Effects of forest biomass use on watershed processes in the western United States. *Western Journal of Applied Forestry* 25(1):12-17.

Elliot, W.J.; Koler, T.E; Cloyd, J.C.; Philbin, M. 1994. Impacts of landslides on an ecosystem. Paper No. 947517. Presented at the 1994 American Society of Agricultural Engineers international winter meeting, Dec. 13-16; Atlanta, GA. St. Joseph, MI: ASAE. 10 pp.

Elliot, W.J.; Hall, D.E., Graves, S.R. 1999a. Predicting sedimentation from forest roads. *Journal of Forestry* 97(8): 23-29.

Elliot, W.J.; Miller I. S. 2002 Estimating erosion impacts from implementing the National Fire Plan. Paper no. 02-5011. Presented at the ASAE Annual International Metting, Jul. 28 – Jul. 31, 2002, Chicago, IL. 26 p.

Elliot, W.J.; Miller, I.S.. 2004. Measuring low rates of erosion from forest fuel reduction operations. Presented at the Annual International Meeting of the ASAE/CSAE, Ottawa, Canada. 1-4 August. St. Joseph, MI: American Soc. of Agric. Engr. 9 p.

Elliot, W.J.; Miller, I.S.; Audin, L., eds. 2010. *Cumulative watershed effects of fuel management in the western United States*. Gen. Tech. Rep. RMRS-GTR-231. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 299 p.

Elliot, W. J.; Tysdal, L.M., 1999b. Understanding and reducing erosion from insloping roads. *Journal of Forestry*. 97(8): 30-34.

Fangmeier, D.D.; Elliot, W.J.; Workman, S.R.; Huffman, R.L.; Schwab, G.O. 2006. *Soil and Water Conservation Engineering, 5th Edition.* Clifton Park, NY: Thomson Delmar Learning. 502 p.

Foltz, R. B. 1994. Sediment reduction from the use of lowered tire pressures. Central tire inflation systems--Managing the vehicle to surface (SP-1061). Paper 942244. Pp. 47-52 Warrendale, PA: Society of Automotive Engineers.

Foltz, R. B. 1996. Traffic and No-Traffic on an Aggregate Surfaced Road: Sediment Production Differences. Proceedings of the Food and Agriculture Organization (FAO) seminar on “Environmentally Sound Forest Road and Wood Transport” Sinaia, Romania, 17-22 June. Rome: FAO. 195-204.

Foltz, R.B.; Copeland, N.; Elliot, W.J. 2009. Reopening Abandoned Forest Roads In Northern Idaho, USA: Quantification of Runoff, Sediment Concentration, Infiltration, and Interrill Erosion Parameters. *Journal of Environmental Management*. 90 (2009): 2542-2550.

Foltz, R. B.; Elliot, W.J. 2001. Infiltration Characteristics of forest road filter windrows. IN Ascough II and D. C. Flanagan. Proceedings of the International Symposium on Soil Erosion Research for the 21st Century. Jan. 3-5, 2001, Honolulu, HA. St. Joseph, MI: ASAE. 13-15.

Foltz, R.B.; Truebe, M. 2003. Locally available aggregate and sediment production. Transportation Research Record: *Journal of the Transportation Research Board* 1919. Paper No. LVR8-1050. 185-193.

Foltz, R.B.; Yanosek, K.A.; Brown, T.M. 2008. Sediment concentration and turbidity changes during culvert removals. *Jour. of Environmental* Mgt 87:329-340.

Gucinski, H.; Furniss, M.J.; Ziemer, R.R.; Brookes, M.H.2001. Forest roads: a synthesis of scientific information. Gen. Tech. Rep. PNWGTR-509. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 103 p.

Hairsine, P.B.; Rose, C.W. 1992. Modeling water erosion due to overland flow using physical principles 2: rill flow, *Water Resources Research* 28(1): 245-250.

Hammond, C.; Hall, D.; Miller, S.; Swetik, P. 1992. Level I Stability Analysis (LISA) Documentation for Version 2.0. Ogden, UT: U.S.D.A. Forest Service, Intermountain Research Station, General Technical Report INT-285, 190p.

Karwan, D.L.; Gravelle, J.A.; Hubbart, J.A. 2007. Effects of timber harvest on suspended sediment loads in Mica Creek, Idaho. *Forest Science* 53(2):181-188.

Ketcheson, G. L.; Megahan W.F. 1996. Sediment Production and Downslope Sediment Transport from Forest Roads in Granitic Watersheds. Research Paper INT-RP-486. Ogden, UT.: USDA Forest Service Intermountain Research Station. 11 p.

Kirchner, J.W.; Finkel, R.C.; Riebe, C.S.; Granger, D.E.; Clayton, J.L.; King, J.G.; Megahan, W.F. 2001. Mountain erosion over 10 yr, 10 k.y., and 10 m.y. time scales. Geology 29(7): 591-594.

Luce, C.H.; Black T.A. 1999. Sediment production from forest roads in western Oregon. *Water Resources Research* 35(8): 2561-2570.

Kimsey, M., Gardner, B., Busacca, A. 2007. Ecological and topographic features of volcanic ash-influenced forest soils. IN Page Dumroese, D Miller, R., Mital, J., McDaniel, P.; Miller, D. tech eds. Procs. Of the workshop on Volcanic-Ash-Derived Forest Soils of the Inland Northwest: Properties and Implications for Management and Restoration. 9-10 Nov. 2005, Coeur d'Alene, ID. Proceedings RMRS-P-44. Fort Collins, CO: U.S. Department of Agriculture Rocky Mountain Research Station. 7 – 21.

Meadows, D; Foltz, R.B.; Geehan, N. 2008. Effects of All Terrain Vehicles on Forested Lands. San Dimas, CA: USDA Forest Service, San Dimas Technology and Development Center. 0823 1811-SDTDC.

McClelland, D.E.; Foltz, R.B.; Wilson, W.D.; Cundy, T.W.; Heinemann, R.; Saurbier, J.A.; Schuster, R.L. 1997. Assessment of the 1995 and 1996 floods and landslides on the Clearwater National Forest. Missoula, MT: USDA Forest Service Northern Region. 52 p.

McDonald, G.I.; Harvey, A.E.; Tonn, J.R. 2000. Fire, competition and forest pests: Landscape treatment to sustain ecosystem function. IN Neuenschwander, L. F., and K. C. Ryan (eds.). Proceedings from the Joint Fire Science Conference and Workshop, Boise, ID. June 15-17, 1999. [Online] 17 p. Available < http:// http://www.fs.fed.us/rm/pubs_other/rmrs_2000_mcdonald_g001.pdf>. [Oct. 2009].

Megahan, W.F.; Day, N.F.; Bliss, T.M. 1978. Landslide occurrence in the Western and Central Northern Rocky Mountain Physiographic Province in Idaho. Procs. Fifth North American Forst Soils Conference, August, Fort Collins, CO: 116-139.

Megahan, W.F.; King, J.G. 2004. Erosion, sedimentation and cumulative effects in the Northern Rocky Mountains. IN Ice, G.G; Stednick, J.D. [Eds.]. A century of forest and wildland watershed lessons. Society of American Foresters. Washington, DC. Elsevier Pub: 201-222.

Reid, L.M. 2010. Cumulative effects of fuel treatment on channel erosion and mass wasting. IN. Elliot, W.J.; Miller, I.S.; and Audin, L. (eds.). *Cumulative Watershed Effects of Fuel Management in the Western United States*. Gen. Tech. Rep. GTR-231. Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station. 102-126.

Reinhardt, E.D., R.E. Keane, D.E. Calkin and J.D. Cohen. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. *Forest Ecology and Mgt* 256: 1997-2006.

Robichaud, P.R. 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. *International Journal of Wildland Fire* 14: 475-485.

Robichaud, P.R.; Elliot, W.J.; Pierson, F.B.; Hall, D. E.; Moffet, C.A. 2007. Predicting postfire erosion and mitigation effectiveness with a web-based probabilistic model. *Catena* 71:229-241.

Robichaud, P.R.; MacDonald, L.H.; Foltz, R.B. 2010. Fuel management and erosion. In: Elliot, W.J.; Miller, I.S.; Audin, L., eds. *Cumulative watershed effects of fuel management in the western United States*. Gen. Tech. Rep. RMRS-GTR-231. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 79-100.

Robichaud, P.R.; Beyers, J.L.; Neary D. G. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. General Technical Report RMRS-GTR-63. Fort Collins, CO: USDA Forest Service Rocky Mountain Research Station. 85 p.

Rummer, B., J. Prestemon, D. May, P. Miles, J. Vissage, R. McRoberts, G. Liknes, W. Shepperd, D. Ferguson, W. Elliot, S. Miller, S. Reutebuch, J. Barbour, J. Fried, B. Stokes, E. Bilek, and K. Skog. 2003. A strategic assessment of forest biomass and fuel reduction treatments in Western States. Online at: http://www.fs.fed.us/research/pdf/Western_final.pdf Accessed 04/10. 18 p.

Wagenbrenner, J.W.; Robichaud, P.R.; Elliot, W.J. 2010. Rill erosion in natural and disturbed forests, part II: modeling approaches. Under Review for Water Resources Research. Moscow, ID: Rocky Mountain Research Station.

Wireman, M. 2000. Hardrock mining. IN Dissmeyer, ed. Drinking Water from Forests and Grasslands A Synthesis of the Scientific Literature. General Technical Report SRS-39. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 179-186.

FIGURES

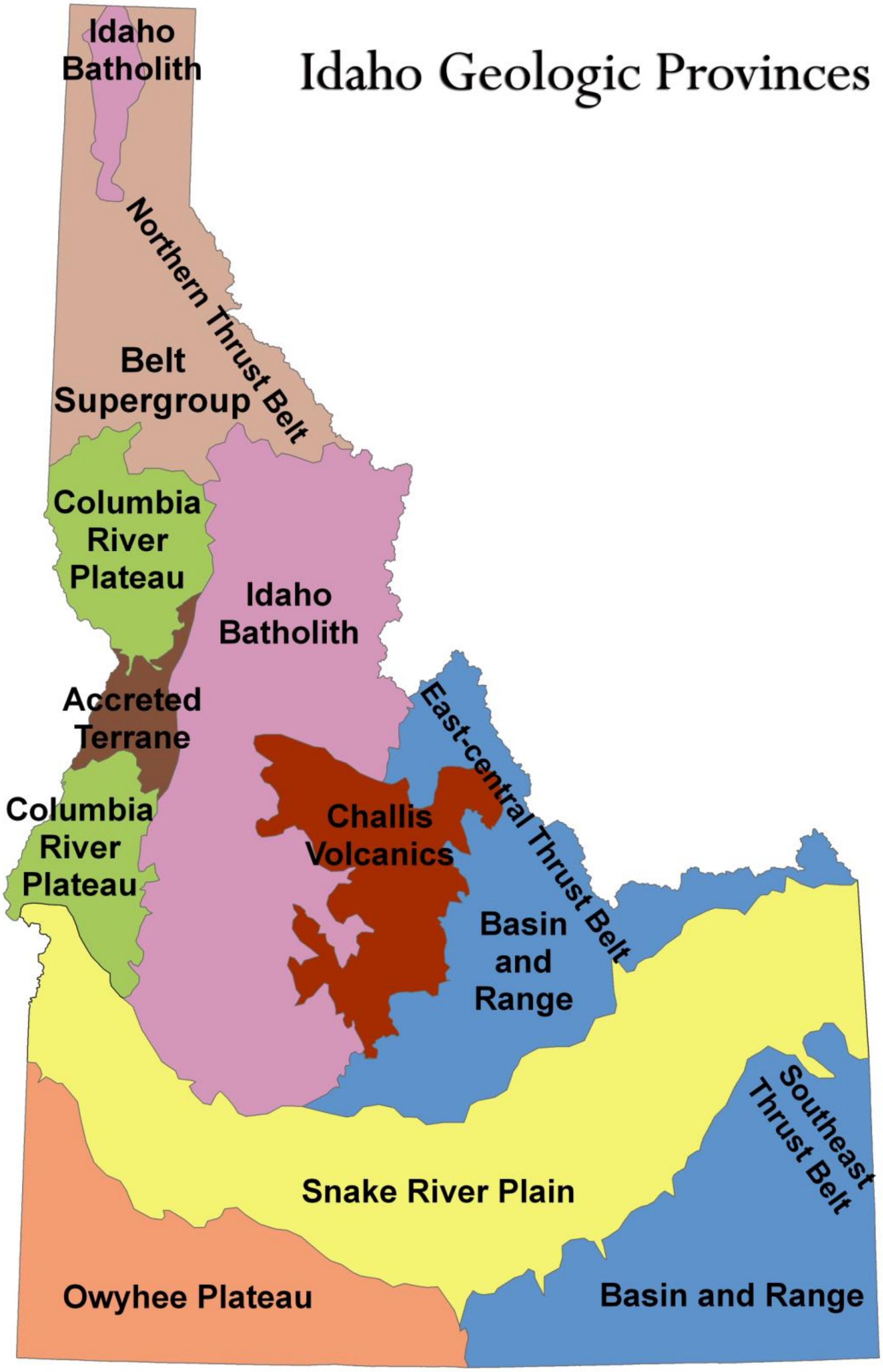

Figure 1. Geologic map of Idaho (Source: http://geology.isu.edu/Digital_Geology_Idaho/Intro/geologic_province_table.htm. Used by permission)

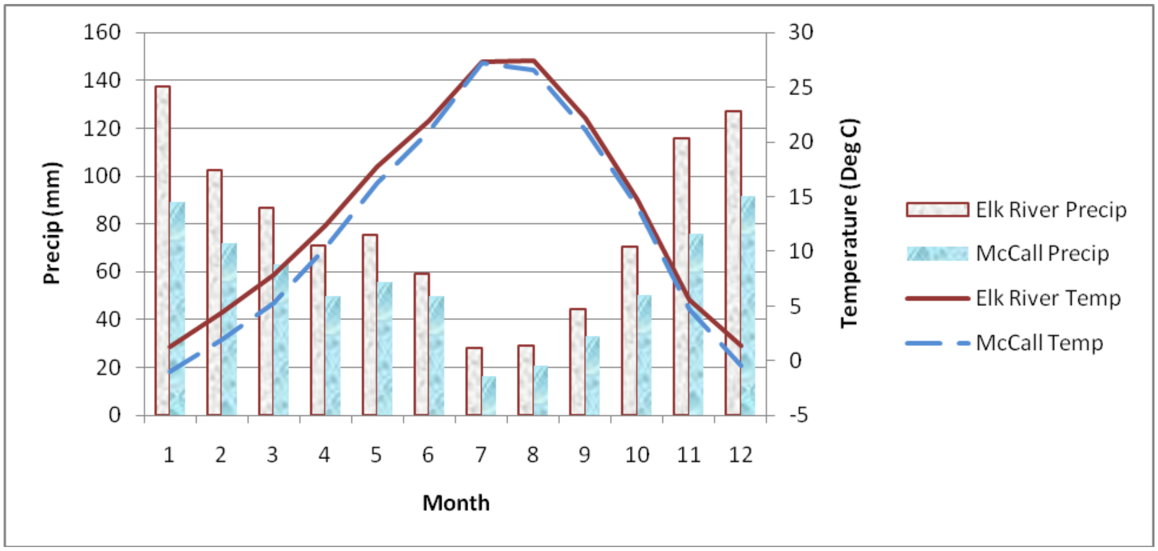

Figure 2. Average monthly precipitation and temperature values for Elk River and McCall, ID (Source: DRI, 2009)

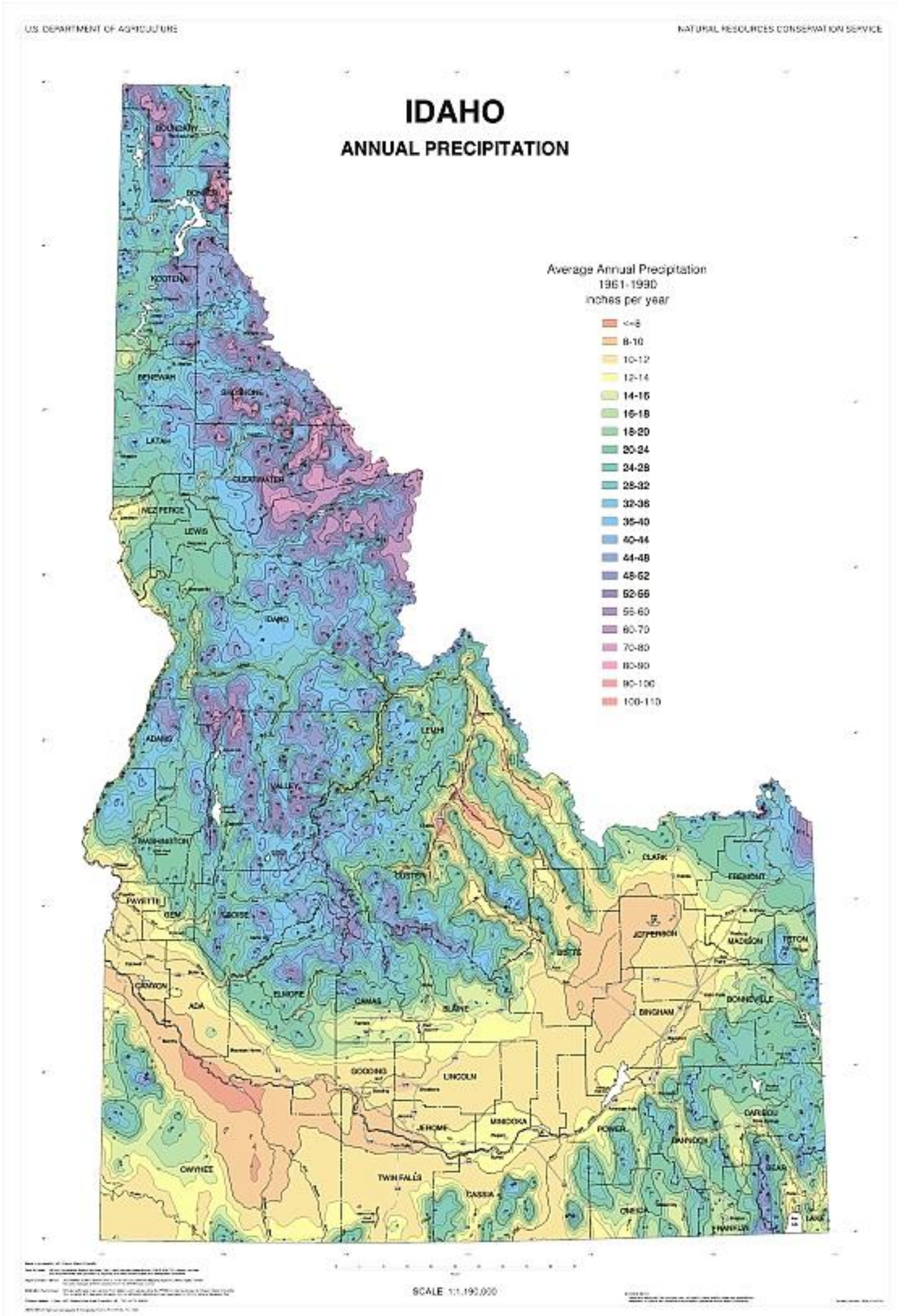

Figure 3. Distribution of average annual precipitation in Idaho (Source: http://www.wrcc.dri.edu/pcpn/prism/id.jpg).

Figure 4. Significant rill erosion following a wildfire (Source: N. Wagenbrenner)

Figure 5. Thinning the understory to reduce hazardous fuels (Source: http://www.flickr.com/photos/22672662@N02/2398486819/)

Figure 6. Fire line around a prescribed burn to reduce ground fuel loads (Source: J. Sandquist)

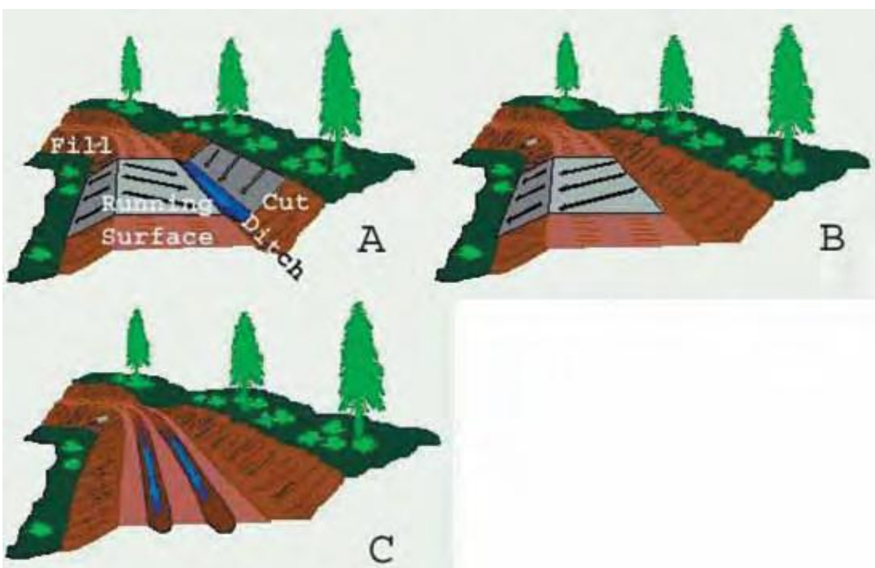

Figure 7. Typical road shapes. A) Insloped; B) Outsloped; and C) Rutted. A crowned road is a combination of insloped and outsloped shapes. Some crowned roads can have a ditch on both sides. (Source: http://forest.moscowfsl.wsu.edu/fswepp/docs/wepproaddoc.html)

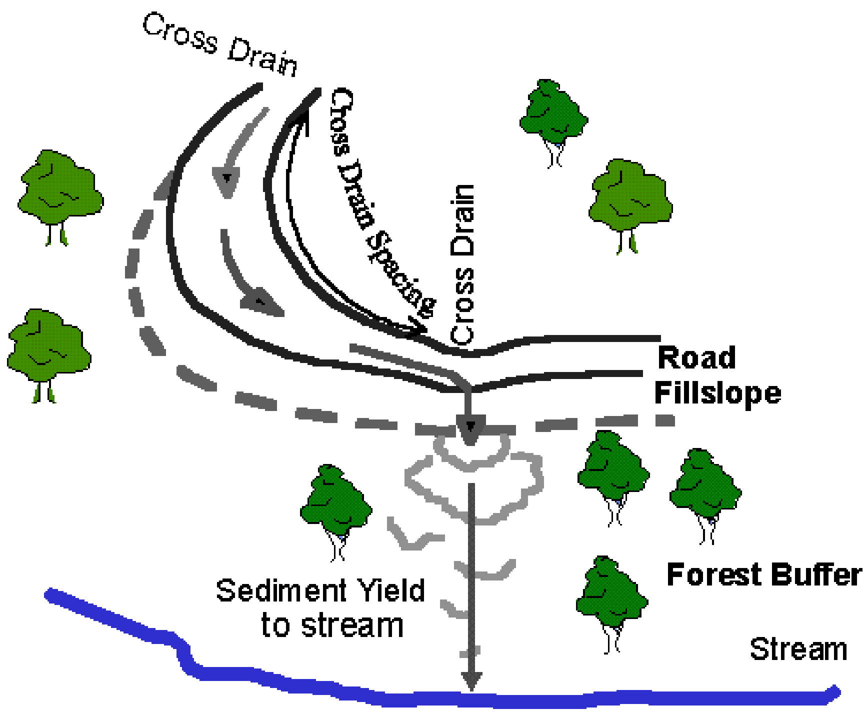

Figure 8. Runoff and sediment is generated on roads, but the runoff infiltrates and the sediment is deposited on the forest buffer (Source: http://forest.moscowfsl.wsu.edu/fswepp/docs/wepproaddoc.html)

Figure 9. Ruts forming on a well maintained road from heavy logging traffic (Source: W. Elliot)

Figure 10. Slash windrow on road fill slope (Source: W. Elliot)

Figure 11. Removing a road in the Clearwater Basin (Source: K. Yanosek (Tyler))

Figure 12. Tracked skidder (Source: http://www.cnr.vt.edu/harvestingsystems/images/TrackedSkidder.jpg)

Figure 13. Rubber-tired skidder lifting the front end of logs while skidding.

Figure 14. Cable logging operation suspends the log as it is delivered to the landing.

Figure 15. Forwarder carrying 10 tonnes of logs from the forest. (Source: http://harveyosity.org/logging/files/Forwarder%20Stacking%20Logs.jpg)

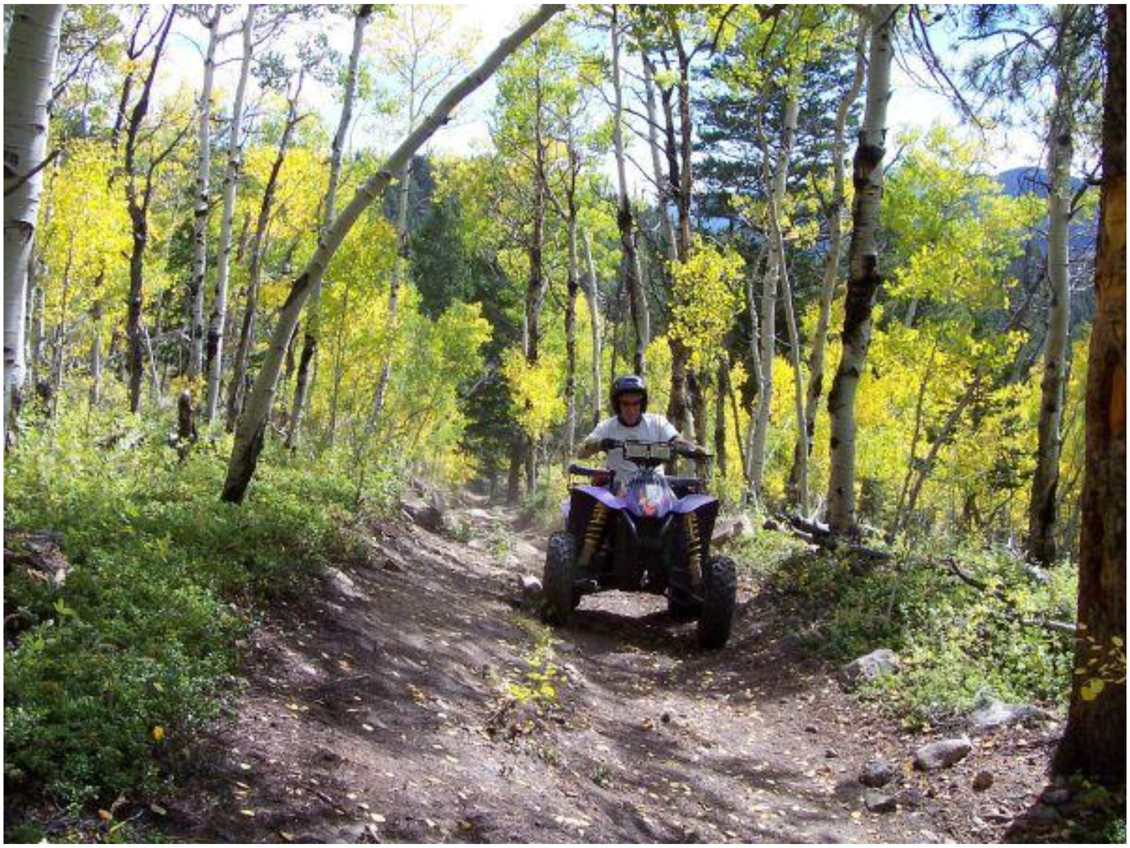

Figure 16. All terrain vehicle on an eroding trail. (Source: http://www.clearcreekcounty.org/ATV)

Figure 17. Shallow landslides on road cut slope and fill slopes in the Nez Perce National Forest. (Source: W. Elliot)

Figure 18. Debris flow in Northern Idaho. This flow was believed to be initiated by a failed road fill due to a collapsed wood culvert (Elliot et al., 1994). (Source: W. Elliot)

Figure 19. Measuring toppled banks on the Upper Truckee River, CA. (Source: W. Elliot)

Appendix D: Enhanced Sediment Delivery in a Changing Climate in Semi-arid Mountain Basins: Implications for Water Resource Management and Aquatic Habitat in the Northern Rocky Mountains

Prepared by Goode et al., 2011

Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains

Jaime R. Goode*, Charles H. Luce, and John M. Buffington

U.S. Forest Service, Rocky Mountain Research Station,

322 E. Front St., Suite 401, Boise, ID 83702, USA

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*Corresponding author. Tel.:+1 208-373-4381; Fax: +1 208-373-4391, E-mail: jaimeg@uidaho.edu

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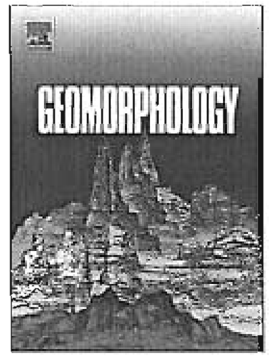

Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains

Jaime R. Goode, Charles H. Luce, John M. Buffington

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Abstract

The delivery and transport of sediment through mountain rivers affects aquatic habitat and water resource infrastructure. While climate change is widely expected to produce significant changes in hydrology and stream temperature, the effects of climate change on sediment yield have received less attention. In the northern Rocky Mountains, we expect climate change to increase sediment yield primarily through changes in temperature and hydrology that promote vegetation disturbances (i.e., wildfire, insect/pathogen outbreak, drought-related die off). Here, we synthesize existing data from central Idaho to explore (1) how sediment yields are likely to respond to climate change, (2) the potential consequences for aquatic habitat and water resource infrastructure, and (3) prospects for mitigating sediment yields in forest basins. Recent climate-driven increases in the severity and extent of wildfire suggest that basin-scale sediment yields within the next few years to decades could be greater than the long-term average rate of 146 T km^{-2} y^{-1} observed for central Idaho. These elevated sediment yields will likely impact downstream reservoirs, which were designed under conditions of historically lower sediment yield. Episodic erosional events (massive debris flows) that dominate post-fire sediment yields are impractical to mitigate, leaving road restoration as the most viable management opportunity for offsetting climate-related increases in sediment yield. However, short-term sediment yields from experimental basins with roads are three orders of magnitude smaller than those from individual fire-related events (on the order of 10^1 T km^{-2} y^{-1} compared to 10^4 T km^{-2} y^{-1}, respectively, for similar contributing areas), suggesting that road restoration would provide a relatively minor reduction in sediment loads at the basin-scale. Nevertheless, the ecologically

damaging effects of fine sediment (material < 6 mm) chronically produced from roads will require continued management efforts.

Keywords: Sediment yield; Climate change; Wildfire; Forest roads; Aquatic habitat, Idaho batholith

1. Introduction

The delivery and transport of sediment through mountain rivers is important to both aquatic ecology and water resource management (Salo and Cundy, 1987; Rice et al., 2001; Dunbar et al., 2010). For fishes and other aquatic biota, the volume and caliber of sediment supplied to a river affect channel morphology, the relative stability of substrate, and the spatial distribution of habitat patches (Cummins and Lauf, 1969; Salo and Cundy, 1987; Montgomery et al., 1996; 1999; Madej and Ozaki, 2009; May et al., 2009). For water resource managers, sediment supply and transport affect water quality, the operational life-span of reservoirs, and the potential for flooding when channels aggrade. While the effects of climate change on water resources have been extensively considered in recent decades (IPCC, 2007), studies examining the physical response of rivers have generally focused on potential changes in hydrology (Dettinger and Cayan, 1995; Barnett et al., 2008; Hamlet and Lettenmaier, 1999; Rajagopalan et al., 2009; Stewart et al., 2004; Milly et al., 2008) and stream temperature (Petersen and Kitchell, 2001; Webb et al., 2008; Isaak et al., 2010), with relatively less investigation of the effects of climate change on sediment yields. Those studies that have been done tend to focus on changes in fluvial transport resulting from climate-driven changes in runoff (e.g., Coulthard and Macklin, 2001; Coulthard et al., 2005; 2008; Boyer et al., 2010; Verhaar et al., 2010), with few studies examining changes in hillslope sediment production to river networks (but see Goudie, 2006; Lane et al., 2008). In mountain basins, we expect climate change to alter sediment yields primarily through changes in temperature and hydrology that promote vegetation disturbances (e.g., wildfire, insect/pathogen outbreak, drought-related die off), which effectively reduce hillslope stability and alter the styles and rates of geomorphic processes that cause erosion (e.g., Bull, 1991).

A growing volume of literature describes recent changes to hydrology in the western US in terms of shifted runoff timing (Cayan et al., 2001; Barnett et al., 2008; Regonda et al., 2005; Stewart, 2009), driven by warming temperatures which have increased rain/snow fractions and increased melt rates (Mote et al., 2005; Knowles et al., 2006). Others have noted declining trends in precipitation and streamflow (Service, 2004; Luce and Holden, 2009; Clark, 2010) or some expectation of future declines (Barnett and Pierce, 2009; Rajagopalan et al., 2009). Such warming and drying trends have also been associated with increased wildfire occurrence and severity (Westerling et al., 2006; Holden et al., 2007; Littell et al., 2009). Although wildfires are well known catalysts for erosion and increased sediment yield in small basins (Meyer et al., 2001; Miller et al., 2003; Istanbulluoglu et al., 2003; Shakesby and Doerr, 2006; Cannon and DeGraff, 2008; Cannon et al., 2010), the potential contribution of climate-driven increases in wildfire activity to the sediment production in large river basins has not been well quantified. Furthermore, little has been documented about the consequences of such changes to aquatic ecosystems or human infrastructure, except at local scales (Benda et al., 2003; Bisson et al., 2003; Lyon and O'Connor 2008; Arkle et al., 2010), leaving many open questions about the potential to adapt water resource and aquatic habitat management strategies to anticipated climate changes.

Despite a relatively limited contemporary literature on climate change and sediment yields in the western US, a combination of mechanistic process studies and paleoenvironmental studies support an understanding that sediment yields in the region could generally increase in a warming and drought-prone environment through effects on vegetation and hydrology (Meyer et al., 1995; Pierce et al., 2004; Istanbulluoglu and Bras, 2006; Collins and Bras, 2008; Whitlock et al., 2008). In light of this general understanding, critical questions concern (1) the expected magnitude of climate-driven changes in sediment yields, at least in a relative sense; (2) the potential consequences for aquatic habitat and water resource infrastructure; and (3) the prospect of ameliorating these changes in sediment yields.

~~Sediment can be beneficial or detrimental to fish and aquatic macroinvertebrates by either~~ providing or polluting habitat (Dunham et al., 2003; Lyon and O'Connor 2008; Arkle et al., 2010). This outcome depends on the timing of delivery, the volume, and the caliber of the sediment, which are contingent on the basin-specific processes and sources that generate sediment. Understanding how processes and rates of sediment delivery might be altered by climate change can give insight about potential stresses on aquatic ecosystems and water resource infrastructure. Furthermore, comparing inputs from natural processes that may be altered in a changing climate to those from land management activities can be used to determine the extent to which detrimental sediment yields can be altered through remediation and watershed restoration.

To explore how changes in the sediment regime might affect aquatic habitat and water resource infrastructure, we examine the natural processes of sediment generation and delivery and consider how these processes will be altered in a changing climate. Because the processes controlling sediment yield ultimately depend on the local context (site-specific climate, geology, topography, vegetation, soils, and land use), we explore the above questions in terms of a case study for central Idaho. This region provides a setting where a number of ecologic and management issues interface, including threatened and endangered salmonids, water supply, and wildfire. Historic sources of sediment also include mining, livestock grazing and logging, but these land uses have been substantially reduced in the study area compared to historic levels (Hessburg and Agee, 2003). Although grazing is currently active in central Idaho, impact levels on forest lands are most likely low in comparison to sediment yields from other disturbances (Trimble and Mendel, 1995; Clayton and Megahan, 1997). Over the last 5 decades, contention over forest management in this region (Megahan et al., 1980) has lead to numerous watershed-based studies of sediment generated from roads and burned areas that we draw upon here (e.g., Megahan and Molitor, 1975; Seyedbagheri et al., 1987; Megahan et al., 2001). To provide context for this discussion, we first review the effects of climate on vegetation, hydrology, and geomorphic processes in semi-arid mountain basins influenced by wildfire.

2. Effects of climate on sediment yield

It is well established that climate exerts a strong external control on landscapes; more importantly, changes in climate promote disturbances and threshold crossing, which ultimately produce some geomorphic response (e.g., Bull 1991). Sediment yields tend to be larger in semi-arid climates than in arid and humid environments due to the regulating effect of vegetation on hillslope stability and soil generation (Langbein and Schumm, 1958; Kirkby and Cox, 1995; Istanbulluoglu and Bras, 2006; Collins and Bras, 2008). Such trends can be conceptualized through the role of climate in moderating the relationship between driving forces (precipitation, weathering/soil formation) and resisting (vegetation type and density) forces (Figure 1). In semi-arid landscapes, the amount of precipitation is sufficient to generate soils and drive erosion, but limits the amount of vegetation growth needed to stabilize hillslopes from erosion. Controlling for the effects of rock type and slope, the climate-related driving forces outweigh the resisting forces in these systems. Because these systems are highly prone to wildfire and other vegetation disturbances, the relationship between driving and resisting forces on hillslopes is further modified by reduced vegetation cover, root strength and soil properties, thereby influencing sediment yields. The size of the vegetation disturbance, as well as the sensitivity of the landscape to changes in vegetation cover, are both factors that govern the change in sediment yield following disturbance (Collins and Bras, 2008), further emphasizing the importance of local context.

The effects of climate change on sediment yield have been demonstrated over different time scales (e.g., Bull, 1991; Knox, 1993; Molnar, 2001; Zhang et al., 2001; Pierce et al., 2004), however contemporary changes in sediment regime may be difficult to detect through conventional measurements of fluvial transport. This is due, in part, to the disparity in temporal resolution between suspended sediment data and stream flow data, which makes detection of transient peaks in concentration without accompanying peaks in flow improbable. For example, weekly or monthly sediment transport samples are not likely to capture a pulse of sediment from a brief thunderstorm over a burned area, and if seen, such an observation would appear as an anomaly compared to the rest of the data, adding apparent uncertainty to the rating curve used to calculate sediment yields. Although methods to continuously sample suspended load are improving, historical data without such measurements may be difficult to compare. Similarly, bedload transport data may be insufficient to detect climatic changes in sediment yield because of low sampling frequency and a paucity of high-flow measurements (e.g., Barry et al., 2008). Furthermore, the inherent temporal variability of sediment transport, especially in supply-limited systems, makes it difficult to statistically test a shift in these rates (e.g., Wilcock, 1992; Ryan and Dixon, 2008). Lacking quantitative measurements of recent climate-forced shifts in sediment yield, we synthesize the available literature to develop a process-based understanding of potential response to climate change in semi-arid basins influenced by wildfire.

2.1. Post-fire erosion and sediment delivery

Wildfires are one of the most important vegetation-altering natural disturbances in western North America, with direct effects on sediment yield (Swanson, 1981; Moody and Martin, 2009). Wildfires promote hillslope instability (landslides and debris flows) and large-scale erosion (rills and gullies) via two dominant mechanisms: removal of vegetation and creation of water-repellent soils (Megahan and Molitor, 1975; DeBano, 2000; Istanbulluoglu et al., 2002; Shakesby and Doerr, 2006). Removal of vegetation lowers erosion thresholds and increases runoff rates. The combined result of these altered processes is commonly a translation of massive amounts of sediment from hillslopes to fluvial systems in episodic pulses, such as landslides and debris flows (Klock and Helvey, 1976; Hooke, 2000; Miller et al., 2003; Cannon and DeGraff, 2008; Moody et al., 2008). Accelerated rates of dry ravel (Roering and Gerber, 2005; Jackson and Roering, 2009) may also be responsible for supplying hollows and low-order channels with additional sediment for transport to the fluvial network via landslides and debris flows (Wells, 1987).

Because wildfire and storm characteristics are important controls on sediment delivery, climate-driven variation in both wildfire and hydroclimate are likely to produce changes in sediment yields. Depending on the local hydroclimatic regime, different types of storms can trigger erosional events: moderately intense frontal systems (Florsheim et al., 1991), high-intensity convective storms (Meyer et al., 1995; Meyer and Wells, 1997; Moody et al., 2008; Cannon et al., 2008; 2010), and winter rain-on-snow events (Meyer et al., 2001, Miller et al., 2003). In these different settings, post-fire debris flows initiate by two primary processes (1) runoff-driven flow concentration and progressive sediment "bulking", causing downstream transitions in rheology from clear-water flow to hyperconcentrated flow, and ultimately the development of a proper debris flow (Meyer et al., 1995; Cannon et al., 2003; 2010; Welker, 2011); and (2) saturation-initiated failure of discrete landslides (Megahan et al., 1978; Meyer et al., 2001; Cannon and Gartner, 2005). In severe fires, post-fire reduction in root cohesion contributes to the later of these two processes (e.g., Swanston, 1971; Burroughs and Thomas, 1977; Schmidt et al., 2001; Jackson and Roering, 2009).

2.2. Climate controls on wildfire

Understanding climate and wildfire variability at different time scales provides an important context for future expectations (Pierce and Meyer, 2008). Wildfire occurrence, frequency, size, and regional synchrony have been shown to correlate with climate variability over different timescales (Swetnam and Betancourt, 1998; Briffa, 2000; Whitlock et al., 2003; Pierce et al., 2004; Marlon et al., 2006; Kitzberger et al., 2007; Trouet, 2010). Paleoclimate studies document millennial-scale climate variability as a dominant factor affecting the history of large wildfires in the western US throughout the Holocene (Whitlock et al., 2003; Pierce et al., 2004). The stratigraphy and charcoal preserved in fire-related alluvial fan deposits show a correspondence between fire severity and Holocene climate variability, further linking climate and wildfire as drivers of sediment delivery (Meyer et al., 1995; Meyer and Pierce, 2003; Pierce et al., 2004).

Over long time scales (> 10^3 y), changes in forest composition complicate the relationship between climate change and wildfire characteristics (size, severity, and frequency). Through its influence on vegetation type, growth rates, and density, climate has an indirect influence on the occurrence and severity of fires (Whitlock et al., 2003). For example, frequent, light surface fires are considered typical of warm, xeric ponderosa pine (*Pinus ponderosa*) forests, whereas less frequent, higher-severity or stand-replacing fires are typical of mesic, subalpine forests dominated by lodgepole pine (*P. contorta*) (Whitlock and Bartlein, 1997; Meyer and Pierce, 2003). As projected changes in climate are expected to be greater in amplitude than those during the Holocene (IPCC, 2007), future fire regimes may also be affected by corresponding vegetation shifts (Brunelle et al., 2005; Gavin et al., 2007). Wildfire occurrence can also restructure forest composition, further altering future fire regimes (Keane et al., 1990; Whitlock et al., 2003; Fisher et al., 2009).

Shorter term (10^2 -10^0 y) climate fluctuations are also associated with wildfire occurrence in the western US. In the southwestern US, for example, interannual, annual, and interdecadal climate variability, driven by the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), are strongly related to drought and wildfire occurrence (Swetnam and Betancourt, 1998; McCabe et al., 2004; Holden et al., 2007). Because low severity fires, burning primarily grasses and understory have historically burned most of the area in these systems, fuel loading can be substantially increased in a few wet years prior to drought (Swetnam and Betancourt, 1998). However, in northern mountain ecoprovinces, (i.e., high elevation subalpine forests, which naturally experience high-severity fires of low frequency) variability in ENSO or climate during antecedent years may not control regional synchrony of fires (Morgan et al., 2008). Instead, large and regionally synchronized fires are more closely related to warm and dry conditions during the year in which they occur (Heyerdahl et al., 2008). This is potentially a result of depleted canopy fuel moisture through climatic preconditioning by low precipitation and high evapotranspiration (Heyerdahl et al., 2008; Morgan et al., 2008; Littell et al., 2009). One of the changes noted in the western U.S. is increased interannual variability in streamflows

(Jain et al., 2005; Pagano and Garen, 2005; Hamlet and Lettenmaier, 2007; Luce and Holden, 2009), suggesting a potential linkage between anthropogenic climate change and more intensely dry years leading to increased wildfire in this region.

2.3 Recent climate change effects on hydrology and wildfire: implications for sediment yields

Over that last five decades in the western US, changes in hydrology indicate a drying of the regional climate and a general warming trend (e.g., Hamlet and Lettenmaier, 1999, 2007; Mote et al., 2005; Luce and Holden, 2009; Clark, 2010). Greater variability in climate and more extremes in temperature and precipitation are also predicted to coincide with this general warming trend (Easterling et al., 2000; Jain et al., 2005; Pagano and Garen, 2005). Specific extremes include more frequent disturbance weather, such as summer drought, and intense storms and floods (Overpeck et al., 1990). Over the next 50 years, drought is expected to be more spatially extensive and intense (Easterling et al., 2007; Hughes and Diaz, 2008; Overpeck and Udall, 2010).

Because of the direct effect of climate change on fire weather (temperature, precipitation, wind, humidity), the extent and frequency of wildfires are expected to increase in the next several decades, as future increases in temperature are likely to extend the fire season throughout the western US and Canada (Gillett et al., 2004; McKenzie et al., 2004; Westerling et al., 2006; Flannigan et al., 2009). Mid-elevation Northern Rockies forests are expected to show the greatest increase in wildfire in response to increased spring and summer temperatures and earlier snowmelt (McKenzie et al., 2004). The combined effect of warming trends and stronger short-term variations in climate, which increase drought, wildfire, and intense storms, will most likely enhance the potential for erosion and sediment delivery through alterations in vegetation, which ultimately control hillslope stability and sediment production. Because a larger range of flood magnitudes are seen in more arid regions (Pitlick, 1994), a climate change toward increased aridity may be expected to correspond to increased erosion rates despite declining annual discharge (Molnar, 2001). If climate change enhances climate variability (Jain et al., 2005; Pagano and Garen, 2005; Luce and Holden, 2009) and leads to more intense and frequent extreme events (Easterling et al., 2000; Hamlet and Lettenmaier, 2007), then such storms could enhance debris-flow occurrence and lead to pulses of sediment, especially when superimposed on the enhanced potential for wildfire, which is already evident from the large area of the western US burned within the last 3 decades (Westerling et al., 2006). Despite human-caused ignition in many cases over this time, climate drivers appear to be the most important control on wildfire occurrence (Westerling et al., 2003).

In an example from the semi-arid shrubland and grassland environments of the Southwestern US, some argue that the cutting and filling cycles of arroyos are driven by vegetation–erosion feedbacks under fluctuating climate (Miller and Leopold, 1961; Balling and Wells, 1990; Hereford, 2002), whereas others have invoked non-climate-related, internal, geomorphic processes (Schumm and Hadley, 1957; Schumm and Parker, 1973). Despite this uncertainty, several cases from the southwestern US illustrate the modulating effect of vegetation response to climate shifts and the subsequent effects on erosion and sediment yield (McFadden and Auliffe, 1997; Hereford, 2002; McAuliffe et al., 2006). Vegetation cover is reduced during dry periods, which primes the landscape by reducing soil strength and leads to gully erosion resulting from flooding during the subsequent wet period.

These processes, although potentially controlled by different driving factors, are analogous to the role that climate variability has on wildfire occurrence in the western US. While the details of the specific processes are different, the indirect pathway through alterations in vegetation is similar. In semi-arid basins of the western US, drought can precondition forests for greater susceptibility to fire. Burned areas are then physically conditioned for either intense summer storms, or rain-on-snow events to drive enhanced erosion and increases in sediment yield, particularly when climate variation enhances the likelihood of stand-replacing fires (Pierce at al., 2004; Cannon and DeGraff, 2008).

3. Potential for management intervention in sediment yields in forested basins

The expectation that sediment yields in semi-arid mountain basins will increase in response to projected warming and increased climate variability, raises a critical and practical question: Is it possible to adjust land management approaches to ameliorate anticipated increases in sediment yield? Potential approaches for reducing sediment through land management include post-fire stabilization, suppression of fire and fire severity, treatment of forest roads, and attention to other anthropogenic sources of sediment (e.g., logging, grazing, mining). Determining the most effective method depends on the relative contribution of each source, management resources and objectives, and feasibility of actions.

Post-fire stabilization is widely held to be ineffective for delivery from major storms (Robichaud et al., 2000), and is generally too expensive and uncertain to be applied beyond short term protection of life and property. Attempting to reduce the role of fire in the landscape through a combination of increased fire suppression and fuel treatments to aid suppression is similarly an expensive and uncertain proposition. Suppressing fire without maintaining reduced fuel levels by alternative means can lead to fuel buildup with negative consequences for subsequent fire control and fire severity (Agee, 1993), which entails ongoing costs. As a consequence, it is most commonly applied near human habitation, in the "wildland-urban interface." Apart from these economic constraints, there are several areas of uncertainty ranging from effectiveness of fuel treatments (Stephens and Moghaddas, 2005), to whether suppression might be effective in a changed climate (Westerling et al., 2006), to tradeoffs between harvest and wildfire in sediment production (Istanbulluoglu et al., 2004), and consequences for aquatic ecosystems (Bisson et al., 2003; Reeves et al., 2006; Rieman et al., 2010).

Given these limitations, mitigation of more discrete land-use related sediment sources may provide the greatest opportunity for land managers to offset the increased sediment yield resulting from widespread vegetation disturbances. In semi-arid basins influenced by wildfire, forest management practices such as timber harvest and wildfire suppression have created unpaved road systems that dissect many watersheds (Gucinski et al., 2001; Jones et al., 2000). Forest roads are widely recognized to increase sediment supplied to forest streams by altering hillslope hydrology and sediment flux (Megahan, 1974; Reid and Dunne, 1984; Ziegler and Giambelluca, 1997; Luce and Black, 1999; Croke and Mockler, 2001; MacDonald et al., 2001; Wemple et al., 2001; Arnáez et al., 2004), thereby reducing water quality and aquatic habitat suitability (Lee et al., 1997). The combined effect of low infiltration capacity of road surfaces (Luce and Cundy, 1994) and interception of surface flow and throughflow by cutslopes (Wemple and Jones, 2003) is increased surface runoff (Luce, 2002), leading to frequent erosion from the road surface (many events per year) and periodic mass failures from the adjacent hillslopes (Montgomery, 1994; Ziegler et al., 2004; Sidle, 2005). Improvement and removal of forest roads is another approach available to land managers to effectively reduce sediment inputs (Luce, 1997; Madej, 2001; Switalski et al., 2004). Although road networks can be extensive, with numerous processes producing sediment to and from roads, the potential reduction in sediment yields available from road mitigation in large basins has not been quantified.

In addition to practices that reduce sediment delivery from roads, management of other anthropogenic sources of sediment (e.g., logging, mining, grazing, agriculture) may further offset climate-related increases in sediment yield. For example, altering the location, type and frequency of logging, as well as treating the site after timber harvest (e.g., replanting hillslopes and decommissioning logging roads), can substantially reduce associated erosion (e.g., Haupt and Kidd, 1965; Swanston, 1970; 1976; Swanson et al., 1987; Gray and Megahan 1981; Chamberlin et al., 1991; Megahan et al., 1992; 1995). As with climate change, increased sediment yields following logging result from vegetation disturbance; exposure of bare soils accelerates surface erosion, loss of forest interception and transpiration increases soil pore pressure, and loss of root strength destabilizes shallow hillslope soils, increasing the potential for shallow landsliding in both humid and semi-arid landscapes (Rice et al., 1969; Swanston, 1970; 1974; Burroughs and Thomas, 1977; Gresswell et al., 1979; Gray and Megahan, 1981; Ziemer, 1981; Sidle et al., 1986; Johnson et al., 2000; Montgomery et al., 2000; Schmidt et al., 2001). Logging roads exacerbate this erosion and commonly produce greater erosion per unit area, but their overall extent is small compared to the area of timber harvest (Megahan, 1986). Although logging has declined in the western US over the last few decades, legacy sediment stored within the fluvial system may continue to affect channel morphology and aquatic habitat (e.g., Megahan et al., 1980; 1992; Madej and Ozaki, 1996), but few mitigation strategies have been developed. Mining activities during the last two centuries in the western US have also created extensive legacy sediment (James, 1991; 1999; Nelson et al., 1991; Wohl, 2006). Protection or removal of mine tailings, stable channel designs, and bank protection using riparian plantings have been used to reduce sediment supplied from historic mining (Kondolf et al., 2002; Densmore and Karle, 2009), while potential failure of tailings ponds, where sediment is retained, may pose a continuous risk, especially in controlling contaminated sediments (Macklin et al., 2006). Managing riparian and floodplain vegetation can also reduce remobilization of contaminated floodplain sediments (Smith, 2004). In addition to mining, livestock grazing has affected sediment yields in the western US over the last two centuries by altering vegetation, hillslope erosion, and streambank stability (Leopold, 1924; Platts, 1981). Strategies for reducing sediment from grazing include livestock exclusion from riparian areas and altering the timing and type of grazing animals (Kauffman and Krueger, 1984; Platts, 1991; Magilligan and McDowell, 1997; Belsky et al., 1999). Whether management efforts can offset climate-change-related increases in sediment yield depends on the relative magnitude, frequency, extent, and character of the above sediment supplies.

4. Implications of changing sediment yields for aquatic habitats

The role of disturbance in shaping aquatic habitats is increasingly recognized and incorporated into several dynamic process concepts in stream ecology, including patch dynamics (Townsend, 1989), the network dynamics hypothesis (Benda et al., 2004b), natural flow regime (Poff et al., 1997), and process domains (Montgomery, 1999). Disturbance is a fundamental component to the life histories of most aquatic species (Resh et al., 1988; Dunham et al., 2003), but whether or not a disturbance is beneficial or detrimental to a particular population depends on the nature of the disturbance. A particular disturbance can be classified as either a 'press' or a 'pulse', according to the duration of the event compared to the lifespan of the longest lived individuals that are affected (Detenbeck et al., 1992). In general, population recovery time is less for pulse disturbances than for press disturbances (Detenbeck et al., 1992; Rieman et al., 1997). As such, the ecological consequences of sediment chronically supplied from roads (press), may be more detrimental than from sediment periodically supplied from post-fire debris flows (pulse).

Nevertheless, debris flows can produce, rapid, dramatic change, causing: (1) extensive channel reorganization along their runout path (Cenderelli and Kite, 1998; Dunham et al., 2007); (2) deposition of massive deposits of sediment and wood at their terminus, frequently expressed as a tributary fan that temporarily blocks or diverts the receiving channel (Benda et al., 2003, 2004a; Lewicki et al., 2006); and (3) a downstream wave of sediment and wood that alters channel morphology, substrate size, and bed stability (Sutherland et al., 2002, Cui and Parker, 2005; Brummer and Montgomery, 2006; Ferguson et al., 2006; Lisle, 2008; Lewicki et al., 2006). Channel aggradation above the debris fan and along the path of the downstream wave of sediment increases flood risk and can destabilize channel morphology. Despite the dramatic nature of debris-flow disturbances and their potential impacts to river corridor infrastructure, salmonids and other aquatic organisms have evolved with, and are adapted to, these disturbances. For example, opportunistic salmonids will spawn along the margins of recently deposited debris fans, which can supply suitable spawning gravels to locations that may otherwise be too coarse for spawning (Lewicki et al., 2006). Similarly, reorganized channels along debris-flow runout paths are rapidly re-colonized by neighboring salmonid populations, with fish exhibiting accelerated rates of maturity in response to living in these hostile environments (i.e., wide, shallow channels with little riparian shade or cover; Rosenberger et al., 2005; 2011). Climate-related increases in the frequency of debris flows could have a positive effect on aquatic populations by increasing the spatial heterogeneity of habitat patches within river networks and promoting greater diversity of species or life histories (Reeves et al., 1995; Bisson et al., 2009). Alternatively, climate-driven changes in the frequency, magnitude, and spatial extent of debris-flow disturbances could negatively impact aquatic populations if these disturbances overwhelm the spatial distribution of a given metapopulation and its ability to absorb such disturbances (Dunham et al., 2003; Miller et al., 2003).

Ecologically, climate-related increases in fine sediment (material < 6 mm) are particularly detrimental. High supplies of fine sediment can fill pools (Lisle and Hilton, 1992; Wohl and Cenderelli, 2000), decrease bed stability (Dietrich et al., 1989; Wilcock, 1998; Lisle et al., 2000), and smother gravel spawning beds (Lisle, 1989), decreasing the survival to emergence of salmonid embryos by reducing intra-gravel flow of oxygen (Everest et al., 1987; Greig et al., 2005; 2007; Lapointe et al., 2004; Tonina and Buffington, 2009), and by entombing alevins (Hausel and Coble, 1976; Bjornn and Reiser 1991). Fine sediment can also impact the growth and survival of juvenile salmonids that have emerged from the streambed (Suttle et al., 2004). The size of fine sediment relative to that of the substrate is an important control on the extent of fine sediment infiltration (e.g., Einstein, 1968; Beschta and Jackson, 1979; Cui and Parker, 1998), as is the rate of sediment supply (Wooster et al., 2008). Fine sediment may comprise a substantial proportion of debris-flow inputs, but the pulsed nature of these events suggests that they are less ecologically damaging than chronic supplies of fine sediment from forest roads.

5. Case study: central Idaho

In forested mountain basins of central Idaho, wildfire and forest roads are the dominant natural and anthropogenic disturbances leading to increased sediment delivery. In the following sections, we synthesize studies from central Idaho in terms of the process-based interactions among climate, wildfire, and hydrology as discussed above to explore questions about how much sediment yield might change, the potential to mitigate those changes, and the relative effects of such efforts on water resource infrastructure and aquatic ecosystems.

5.1. Physical setting

The study area is characterized by steep mountainous terrain underlain by a variety of rock types that locally influence the volume and caliber of sediment supply, but is dominated by the Idaho batholith, which is characterized by coarse-textured, highly erodible granitic soils, and regolith-mantled hillslopes (Figure 2; Clayton and Megahan, 1997). Wildfires are an important natural disturbance in this region. Combined with the above hillslope characteristics, extreme post-fire runoff and mass failures tend to produce a large proportion of the overall sediment yield (Meyer et al., 2001). Similar to other mountain basins in western North America, the hydrology is dominated by snow processes, with a summer-dry period (Whitlock and Bartlein, 1993; Whitlock et al., 2008; Moody and Martin, 2009). A substantial portion of the basins in central Idaho are within National Forests, where management issues include: wildfire, water supply, and aquatic ecology. Historic anthropogenic disturbances also include mining, grazing, and logging. Although legacy sediments from these activities may contribute to sediment yields in this region, it is difficult to isolate this sediment from current sources, limiting potential management. This region of central Idaho encompasses the headwaters for water supply to much of the Salmon River Basin (the principal tributary to the lower Snake River) and important downstream water resource infrastructure (the four lower Snake River dams: Lower Granite, Little Goose, Monumental, and Ice Harbor, Figure 2). Increased sediment yields from these basins, therefore, have societal consequences, such as reservoir sedimentation and potential flooding near major dams along the lower Snake River. Of the 84,370 km^2 total area contributing sediment to the lower Snake River, 21% is designated wilderness, and 35% is non-wilderness National Forest (Figure 2). The Salmon River and Clearwater River (excluding the impounded North Fork

Clearwater), comprise a total of 64% of the basin contributing sediment to the lower Snake River.

5.2. Potential effects of climate change on sediment yields in central Idaho

The potential for climate change to alter sediment yields in large basins within central Idaho is conceptualized in Figure 3 in terms of interactions between changes in hydroclimate, wildfire, and the dominant erosional processes. As described earlier, climate change is expected to increase wildfire size and severity in semi-arid basins of the western US. In central Idaho, a trend is already apparent from the large area burned within the last 10-20 years (Figure 2; Westerling et al., 2006; Pierce and Meyer, 2008).

Changes in the magnitude of sediment yield due to recent increases in wildfire activity in central Idaho could be surprisingly large compared to short-term yields reported for the 1920's-2000's (Figure 4). The short-term yields are about an order of magnitude smaller than estimates of long-term erosion rates determined from cosmogenic analysis of fluvial sediments (Figure 4). Although these differences may stem, in part, from methodology, they more likely result from differences in the length of record for each approach and a lack of fires throughout the study area for most of the 20th century (Morgan et al., 2008). Istanbulluoglu et al. (2004) demonstrated that the mechanism driving higher long-term sediment yields in smaller catchments (< 25 km^2) was rare, post-fire, erosional events (recurrence intervals on the order of 100-200 yrs.) that are typically 2 orders of magnitude larger than the long-term average yields (Figure 4), and are followed by long periods of relative quiescence. In the last decade, over 20% of the basin has experienced stand-replacing fires, many of which have led to post-fire debris flows (Meyer et al., 2001; Shaub, 2001; Istabulluoglu et al., 2003; Miller et al., 2003; Lewicki et al., 2006; Cannon et al., 2010). This suggests that the next few years to decades could see basin-scale sediment yields close to or possibly above the long-term average rate of 146 T $km^{-2} y^{-1}$; values substantially larger than recent short-term yields that likely represent a period of wildfire quiescence (Figure 4).

Climate change is also expected to alter the storms that drive hillslope erosion and mass failures following fire (Figure 3). In central Idaho, both high-intensity, short-duration thunderstorms in the summer and rain-on-snow events in the winter at intermediate elevations can drive subsequent erosion and mass wasting events (Meyer et al., 2001; Miller et al., 2003). In the western US, the largest reduction in the fraction of precipitation falling as snow has occurred at locations of moderate warming near typical rain-snow transitions (Knowles et al., 2006). Given the relatively large proportion of terrain in central Idaho at intermediate elevations (Tennant and Crosby, 2009), and that 60% of the increase in large wildfires over the last several decades has occurred in mid-elevation forests of the Northern Rockies where fire suppression has had little effect (Westerling et al., 2006), such warming and hydroclimatic shifts may increase sediment yields through regional synchrony in processes. Furthermore, intermediate-elevation slopes in central Idaho are commonly steeper than the rest of the terrain, enhancing the potential for increased post-fire sediment production from rain-on-snow events (Miller et al., 2003).

In addition to affecting the processes driving sediment delivery to streams from hillslopes, climate-related changes in basin hydrology can modify the transport and distribution of sediment through the fluvial network, which can have direct implications for downstream infrastructure and water resource management. Much of the study area is composed of steep, confined channels that are competent to transport coarse bed load material during typical flood events (i.e., bankfull discharge; Figure 5). However, bed load transport in coarse-grained rivers is a slow process, with material typically moving short distances (on the order of a fraction to tens of channel widths) during typical flood events (Hassan and Church, 1992; Gintz et al., 1996; Haschenburger and Church, 1998; Ferguson et al., 2002; Lenzi, 2004; Lamarre & Roy, 2008). Furthermore, lower-gradient unconfined reaches within the stream network have low competence (Figure 5, circled reaches) and are long-term sediment storage zones, effectively slowing down bed load transport rates through the system. Depending on the spatial extent of these low-gradient unconfined reaches within a given study region, climate-driven changes in the supply and transport of bed load material may not be realized to downstream reservoirs for centuries to millennia.

However, the bulk of fluvial sediment yields are composed of suspended- and wash-load material (sands and silts), which will be rapidly transported through mountain river networks (Whiting et al., 2005) to downstream infrastructure. The supply of this type of material is particularly high in the Idaho batholith due to the abundance of sparsely-vegetated, grussy soils. Hence, climate-related increases in the supply and transport of fine material could significantly impact reservoir capacity and operation within the lower Snake River basin during operational time scales.

Increased sediment yields resulting from climate change also have the potential to overwhelm channel transport capacity, causing aggradation and morphologic adjustment, particularly for alluvial response reaches (Montgomery and Buffington, 1997; Pierce et al., 2011). Climate-driven reductions in streamflow and transport capacity could further exacerbate such response, but may be offset to some degree by increased flow variability and more frequent occurrence of floods larger than the mean annual value, which should promote increased sediment transport and more dynamic channel conditions (Molnar, 2001; Andrews and Vincent, 2007; Buffington, in press). Data from the study area indicate that these mountain channels are currently supply limited, offering some resilience to increased sediment loads (Figure 6). In general, the significance of climate-driven changes in sediment supply and transport capacity depend on the initial conditions of the system (supply- vs. transport-limited), proximity to the threshold between these two states (solid line in Figure 6), and whether climate change causes the system to switch states (cross the threshold). Within central Idaho, areas with the greatest potential for state transition are the lower-gradient and lower-competence reaches (Figure 5).

5.3. Potential to ameliorate changes in sediment yield in the face of climate change

Climate-related changes in sediment yield for the study area offer challenges to managers of both aquatic ecosystems and water resource infrastructure. Watersheds in central Idaho host several threatened and endangered aquatic species, while providing the source waters for large infrastructure on the lower Snake River. For aquatic managers, an increase in the spatial coverage and temporal frequency of major disturbances has unknown consequences, although theoretical and recent empirical evidence suggests the changes could be relatively benign because of the pulsed nature of these events (Dunham et al., 2003; Bisson et al., 2009). Increased chronic supplies of fine sediment from roads, however, could be detrimental. For managers of downstream water resource infrastructure, issues with reservoir sedimentation, including the increased potential for flooding near the head of reservoirs receiving sediment, poses an even greater challenge (Dunbar et al., 2010). Although engineering solutions may be available, seeking joint benefit through restoration and suppression of sediment yields from upstream landscapes poses an intriguing option.

A critical question is whether landscape restoration focused on land management activities or wildfire offers practical reductions in sediment loads. Although land management activities, particularly those associated with forest harvest and roads have long been held as dominant sediment sources in forested landscapes (Brown and Krygier, 1971; Megahan and Kidd, 1972; Reid et al., 1981; Grayson et al., 1993; MacDonald et al., 1997; Ziegler et al., 2000; Motha et al., 2003), there seems to be an equal recognition of the substantial contribution from individual fires (Brown and Krygier, 1971; Megahan and Molitor, 1975; Klock and Helvey, 1976; Shakesby and Doerr, 2006; Moody et al., 2008). The utility of restoration actions depends on our ability to mitigate erosion from various sources and their relative contributions to the sediment budget.

As noted earlier, the general potential for reduction of sediment yields by suppressing delivery from forested hillslopes through a combination of fuel treatments, fire suppression, and post-fire erosion stabilization is limited. This potential is further decreased by the large area of designated wilderness in central Idaho (Figure 2; 21% of the basin contributing sediment to the lower Snake River). Furthermore, an understanding of coupled forest and aquatic ecosystems leads us to recognize that it might be an ecologically misdirected effort (Miller and Urban, 2000; Rieman et al., 2010). Climatic disturbances such as drought have played a long-term role in both regulating fuel supplies and fire regimes (Pierce and Meyer, 2008), and the associated hillslope disturbances have been important for replenishing gravels and wood for aquatic ecosystems (Reeves et al., 1995). This leaves road restoration as an outstanding opportunity for reducing sediment yields in ways that could benefit both aquatic ecosystems and reservoir managers. Furthermore, reduced snow cover duration in a warmer climate (Barnett et al., 2008; Brown and Mote, 2009) is likely to increase the period of snow free conditions on forest roads and time available for sediment production, supporting the need for road improvement or removal.

We can return to Figure 4 for some insights about the potential reductions of sediment yield from roads. In the short term, sediment yields from individual fire-related events in this region are three orders of magnitude greater than those from experimental basins with roads (on the order of 10^4 T km^{-2} y^{-1} compared to 10^1 T km^{-2} y^{-1}, respectively; Figure 4). Comparisons at longer time scales require consideration of the episodicity of fire-related events, recalling that long-term sediment yields are likely controlled by rare, post-fire erosional events (Istanbulluoglu et al. 2004). Short-term sediment yields during the 1950's-1980's (measured from basins without fire, but with some containing forest harvest and roads) were 17 times lower than the longer-term rates across a large range of basin area scales (Figure 4). Thus, the time-averaged effect of wildfire on sediment yields is still generally expected to be greater than the short-term effect of roads, suggesting that road restoration would provide a relatively minor reduction in sediment loads. In addition, short-term sediment yields from basins with forest roads were not substantially larger than basins without roads (Figure 4), further illustrating the small effect of forest roads on basin-averaged sediment yields.

Estimates separating road erosion from total catchment yields reinforce this view. In a before-after-control-impact study of two treated basins and one control, road erosion contributing to the basin-average yield (including cut, fill, and road surface erosion) over the first four years following construction was 12 T km^{-2} y^{-1} and 7 T km^{-2} y^{-1} for 1.2 km/km^2 and 2.4 km/km^2 of road, respectively (Ketcheson et al., 1999, red triangles in Figure 4), compared to 2.5 T km^{-2} y^{-1} for the control basin. Consequently, roads roughly double the sediment yield from small, undisturbed catchments at this level of road density. Because the first few years after road construction have the highest erosion rates (Megahan, 1974), they represent a high estimate of the potential for sediment contribution from roads. However, roads that have been in place for a number of years offer more typical opportunities for sediment reduction. Modeling of road erosion in the South Fork Payette River Basin (Prasad, 2007) provides further estimates of road contributions. Modeling was performed with a set of GIS-based analysis tools called Geomorphologic Road Analysis and Inventory Package (GRAIP; Black et al., 2010), which distributes sediment eroded from individual road segments based on measured rates of road-surface erosion applied to relationships from Luce and Black (1999, 2001a,b) and the Washington Forest Practices Board (1995). The resulting sediment yields shown in Figure 4 are updated from Prasad (2007) based on measurements of road-surface erosion from the Middle Fork Payette watershed (T. Black, unpub. data). Roads can contribute substantial amounts of sediment relative to undisturbed forests, but these inputs are small relative to fire-related sediment yields (Figure 4). The most heavily roaded sub-watershed (6^{th} field Hydrologic Unit), Rock Creek (44 km^2), was predicted to have about 3.5 T km^{-2} y^{-1} of road-derived surface erosion for a road density of 2.5 km/km^2; two orders of magnitude smaller than the long-term sediment yield related to fire (Figure 4).

Although forest roads in this region have been associated with large sediment inputs resulting from mass wasting events (e.g., Megahan and Kidd, 1972; Montgomery, 1994; Ketcheson and Megahan, 1996; Colombaroli and Gavin, 2010), they are typically singular events and it is difficult to generalize from small samples to estimate the amount of sediment generated from these events over larger basins. Many studies discussing landslides and roads refer to older road building methods that are no longer practiced (e.g. Megahan and Kidd, 1972; Wemple et al., 2001; Keppeler et al., 2003), suggesting the potential for lower sediment production from road-related mass wasting than in the past. Supporting evidence comes from landslide surveys within the South Fork Salmon River. In one area of historical roads, 77% of 89 landslides were attributed to roads in response to two large precipitation events in the winter and spring of 1964-1965 (Jensen and Cole, 1965 as summarized by Seyedbagheri et al., 1987). In a 1997 survey covering a much larger area of the South Fork Salmon, after a similar precipitation event the preceding winter, only 7% of the landslides were from roads (Miller et al., 2003). Without adjusting for area and hydroclimatic events in these two studies, it is difficult to generalize. Nonetheless, the strong contrast in percentage of landslides attributed to roads between these cases suggests that mass wasting resulting from forest roads contributes less sediment now than in the past, which is most likely a response to improved construction and maintenance practices and a decrease in new road construction. An important caveat is that an increasing backlog of unmaintained roads may present a continuing, if not increasing, hazard (Keppeler et al., 2003), unless decommissioning efforts are pursued.

Furthermore, if we compare the spatial coverage of roads versus burned areas in central Idaho, forest roads cover substantially less area than recent burned areas due, in part, to the extensive designated wilderness. Even in the more heavily managed basins, road coverage is highly variable, with management activity typically focused on a few small areas. As an example, maps from the South Fork of the Salmon River, which has one of the highest basin-average road densities in the region, and a substantial history of forest management (Megahan et al., 1980), show that the amount of area burned is much greater than the area containing road networks (Figure 7). Furthermore, the fact that roads are distributed in a clustered fashion (Figure 7), suggests that while road restoration could locally change the sediment supply in basins with high road concentrations, it is unlikely to detectably alter sediment supplies in basins greater than a few hundred square kilometers simply because the overall road density at that scale is limited.

6. Conclusions

Coniferous forests across western North America are experiencing widespread mortality as a result of drought, insect outbreaks, and wildfire associated with climate change (Breshears et al., 2005; Adams et al., 2009; van Mantgem et al., 2009; Allen et al., 2010). In many of these landscapes, wildfires and subsequent storms commonly result in the delivery of large, infrequent pulses of sediment to fluvial systems. Climate-modulated interactions among vegetation, wildfire, and hydrology suggest that sediment yields will likely increase in response to climate change. Within central Idaho, recent climate-driven increases in wildfire burn severity and extent have the potential to produce sediment yields roughly 10-times greater than those observed during the 20^{th} century. Although coarse sediment is important for forming aquatic habitats, an order of magnitude increase in total sediment yields may have short-term negative consequences to biota, many of which are already threatened and endangered due to a long history of anthropogenic disturbance (Nehlsen et al., 1991; Montgomery, 2003). In addition, these elevated sediment yields are probably outside of the range of expectations for downstream reservoirs, which may have consequences for reservoir management and life expectancy.

Because downstream aquatic ecosystems and water resource infrastructure may be sensitive to these changes in sediment yield, there is interest in the potential benefits of large-scale landscape restoration practices to reduce sediment, either through reduction of fire-related sediment or road decommissioning and improvement. Improved grazing management may be a potential option to reduce sediment, but a lack of discussion of grazing related sediment yields in the literature (Trimble and Mendel, 1995; Clayton and Megahan, 1997), suggests a limited potential when compared to road management. Similar to roads, however, local impacts of grazing on channel morphology and sediment delivery can be substantial, and those impacts are the primary focus of current management for aquatic habitat (e.g., Kershner et al., 2004). Future research on the cumulative effects of grazing on basin-scale sediment yield would improve management decisions focused at this scale. A growing body of literature is discouraging further interference in natural landscape disturbance processes, such as fire and post-fire erosion, because the dynamic response to such disturbances may help maintain more diverse ecosystems that are more resilient to changed climates (Dunham et al., 2003; DellaSala et al., 2004). There is also substantial uncertainty about the efficacy of pre- and post-fire treatments for vegetation and hillslope erosion in forested mountain basins (Robichaud et al., 2000). In contrast, road decommissioning is recognized as being largely successful (Switalski et al., 2004). Unfortunately a comparison of sediment inputs from roads contrasted to both the short- and long-term regional sediment yields expected from fire suggest that road decomissioning would do little to decrease the total supply. However, road decommissioning would likely hold local benefits for aquatic ecosystems in terms of reducing detrimental fine sediment inputs.

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References

Adams, H.D., Guardiola-Claramonte, M. Barron-Gafford, G.A., Camilo Villegas, J., Bershears, D.D., Zou, C.B., Troch, P.A., Huxman, T.E., 2009. Temperature sensitivity of drought-induced tree mortality portends increased regional die-off under global-change-type drought. Proceedings of the National Academy of Sciences 106, 7063-7066.

Agee, J.K., 1993. Fire Ecology of Pacific Northwest Forests, Island Press, Washington DC.

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D.D., Hogg, E.H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., Lim, J., Allard, G., Running, S. W., Semerci, A., Cobb, N., 2010. A global review of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259, 660-684.

Andrews, E.D., Vincent, K.R., 2007. Sand deposition in shoreline eddies along five wild and scenic rivers, Idaho. River Research and Applications 23, 7-20.

Arkle, R.S., Pilliod, D.S., Strickler K., 2010. Fire, flow and dynamic equilibrium in stream macroinvertebrate communities. Freshwater Biology 55, 299-314.

Arnáez, J., Larrea, V., Ortigosa, L., 2004. Surface runoff and soil erosion on unpaved forest roads from rainfall simulation tests in northeastern Spain. Catena 57, 1-14.

Balling, R.C., Wells, S.G., 1990. Historical rainfall patterns and arroyo activity within the Zuni River drainage basin, New Mexico. Annals of Association of American Geographers 80, 606–617.

Barnett T.P., Pierce, D.W., 2009. Sustainable water deliveries from the Colorado River in a changing climate. Proceedings of the National Academy of Sciences of the USA 106, 7334-7338.

Barnett, T.P., Pierce, D.W., Hidalgo, H.G., Bonfils, C., Santer, B.D., Das, T., Bala, G., Wood, A.W., Nozawa, T., Mirin, A.A., Cayan, D.R., Dettinger, M.D., 2008. Hunan-induced changes in the hydrology of the western United States. Science 319, 1080-1083.

Barry, J.J., Buffington, J.M., King, J.G., 2004. A general power equation for predicting bed load transport rates in gravel bed rivers. Water Resources Research 40, W10401.

Barry, J.J., Buffington, J.M., Goodwin, P., King, J.G., Emmett, W.W., 2008. Performance of bed load transport equations relative to geomorphic significance: Predicting effective discharge and its transport rate. Journal of Hydraulic Engineering 134, 601-615.

Belsky, A.J., Matzke, A., Uselmen, S., 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54, 419-431.

Benda, L., Miller, D., Bigelow, P., Andras, K., 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. Forest Ecology and Management 178, 105-119.

Benda, L., Andras, K., Miller, D., Bigelow, P., 2004a. Confluence effects in rivers: Interactions of basin scale, network geometry, and disturbance regimes. Water Resources Research 40, W05402.

Benda, L., Poff, N.L, Miller, D., Dunne, T., Reeves, G., Pess, G., Pollock, M., 2004b. The network dynamics hypothesis: How channel networks structure riverine habitats. BioScience 54, 413-427.

Beschta, R.L., Jackson,W.L., 1979. The intrusion of fine sediments into a stable gravel bed. Journal of Fisheries Research Board of Canada 36, 204-210.

Bisson, P.A., Rieman, B.E., Luce, C., Hessburg, P.F., Lee, D.C., Kershner, J.L., Reeves, G.H., Gresswell, R.E., 2003. Fire and aquatic ecosystems of the western USA: Current knowledge and key questions. Forest Ecology and Management 178, 213-229.

Bisson, P.A., Dunham, J.B., Reeves G.H., 2009. Freshwater ecosystems and resilience of Pacific salmon: Habitat management based on natural variability. Ecology and Society 14, 45.

Bjornn, T.C., Reiser, D.W., 1991. Habitat requirements of salmonids in streams. In: Meehan, W.R. (Ed.), Influence of Forest and Rangeland Management on Salmonid Fishes and

Their Habitats. American Fisheries Society Special Publication 19, Bethesda, MD, pp. 83-138.

Black, T.A., Cissel, R.M., Luce, C.H., 2010. The geomorphic road analysis and inventory package (GRAIP) data collection method. USDA Forest Service, Rocky Mountain Research Station, <http://www.fs.fed.us/GRAIP/downloads/manuals/GRAIP_ManualField2010.pdf>, last accessed 28 August, 2010.

Boyer, C., Verhaar, P.M., Roy, A.G., Biron, P.M., Morin, J., 2010. Impacts of environmental changes on the hydrology and sedimentary processes at the confluence of St. Lawrence tributaries: Potential effects on fluvial ecosystems. Hydrobiologia 647, 163-183.

Breshears D.D., Cobb, N.S., Rich, P.M., Price, K.P., Allen, C.D., Balice, R.G., Romme, W.H., Kastens, J.H., Floyd, M.L., Belnap, J., Anderson, J.J., Myers, O.B., Meyer, C.W., 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the USA 102, 15144-15148.

Briffa, K.R., 2000. Annual climate variability in the Holocene: Interpreting the message of ancient trees. Quaternary Science Reviews 19, 87-105.

Brown, G.W., Krygier, J.T., 1971. Clearcut logging and sediment production in the Oregon Coast Range. Water Resources Research 7, 1189-1198.

Brown, R.D., Mote, P.W., 2009. The response of Northern Hemisphere snow cover to a changing climate. Journal of Climate 22, 2124-2145.

Brummer, C.J., Montgomery, D.R., 2006. Influence of coarse lag formation on the mechanics of sediment dispersion in a mountain stream, Squire Creek, North Cascades, Washington, United States. Water Resources Research 42, W07412.

Brunelle, A., Whitlock, C., Bartlein, P.J., Kipfmeuller, K., 2005. Holocene fire and vegetation along environmental gradients in the Northern Rocky Mountains, Quaternary Science Reviews 24, 2281-2300.

Buffington, J.M., in press. Changes in channel morphology over human time scales. In: Church, M., Biron, P., Roy, A. (Eds.), Gravel-Bed Rivers: Processes, Tools, Environments. Wiley, Chichester.

Bull, W.B., 1991. Geomorphic Responses to Climate Change. Oxford University Press, New York.

Bull, W.B., 1997. Discontinuous ephemeral streams. Geomorphology 19, 227-276.

Burroughs, E.R., Thomas, B.R., 1977. Declining root strength in Douglas-fir after felling as a factor in slope stability, USDA Forest Service, Intermountain Forest and Range Experiment Station Research Paper INT-190, 27 pp.

Cannon, S.H., DeGraff, J., 2008. The increasing wildfire and post-fire debris-flow threat in western USA, and implications for consequences of climate change. In: Sassa, K., Canuti, P. (Eds.), Landslides – Disaster Risk Reduction, Proceedings of 1st World Landslide Forum. Springer-Verlag, Berlin, pp. 177-190.

Cannon, S.H., Gartner, J.E., 2005. Wildfire-related debris flow from a hazards perspective. In: Hungr, O., Jacob, M. (Eds.), Debris Flow Hazards and Related Phenomena. Praxis, Springer-Verlag, Berlin, pp. 363–385.

Cannon, S.H., Gartner, J.E., Parrett, C., Parise, M., 2003. Wildfire-related debris-flow generation through episodic progressive sediment-bulking processes, western USA. In: Rickenmann, D., Chen, C. (Eds.), Debris-Flow Hazards Mitigation: Mechanics, Prediction, and Assessment. Millpress, Rotterdam, pp. 71-82.

Cannon, S.H, Gartner, J.E., Wilson, R.C., Bowers, J.C., Laber, J.L., 2008. Storm rainfall conditions for floods and debris flows from recently burned areas in southwestern Colorado and southern California. Geomorphology 96, 250-269.

Cannon, S.H., Gartner, J.E., Rupert, M.G., Michael, J.A., Rea, A.H., Parrett, C., 2010. Predicting the probability and volume of postwildfire debris flows in the intermountain western United States. Geological Society of America Bulletin 122, 127-144.

Cayan, D.R., Kammerdiener, S.A., Dettinger, M.D., Caprio, J.M., Peterson, D.H., 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society 82(3), 399-415.

Cenderelli, D.A., Kite, S., 1998. Geomorphic effects of large debris flows on channel morphology at North Fork Mountain, eastern West Virginia, USA. Earth Surface Processes and Landforms 23, 1-19.

Chamberlin, T.W., Harr, R.D., Everest, F.H., 1991. Timber harvesting, silviculture, and watershed processes. In: Meehan, W.R. (Ed.), Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19, Bethesda, MD, pp. 181-205.

Clark, G.M., 2010, Changes in patterns of streamflow from unregulated watersheds in Idaho, western Wyoming, and northern Nevada. Journal of the American Water Resources Association 46, 486-497.

Clayton, J.L., Megahan, W.F., 1997. Natural erosion rates and their prediction in the Idaho batholith. Journal of American Water Resources Association 33, 689-703.

Collins, D.B.G., Bras, R.L., 2008. Climate control of sediment yield in dry lands following climate and land cover change. Water Resources Research 44, W10405.

Colombaroli, D., Gavin, D.G., 2010. Highly episodic fire and erosion regime over the past 2,000 y in the Siskiyou Mountains, Oregon. Proceedings of the National Academy of Sciences of the USA 107, 18909-18914.

Coulthard, T.J., Macklin, M.G., 2001. How sensitive are river systems to climate and land-use changes? A model-based evaluation. Journal of Quaternary Science 16, 347-351.

Coulthard, T.J., Lewin, J., Macklin, M.G., 2005. Modelling differential catchment response to environmental change. Geomorphology 69, 222-241.

Coulthard, T.J., Lewin, J., Macklin, M.G., 2008. Non-stationarity of basin scale sediment delivery in response to climate change. In: Habersack, H., Piégay, H., Rinaldi, M. (Eds.), Gravel-Bed Rivers VI: From Process Understanding to River Restoration. Elsevier, Amsterdam, pp. 315-329.

Croke, J., Mockler, S., 2001. Gully initiation and road-to-stream linkage in a forest catchment, southeastern, Australia. Earth Surface Processes and Landforms 26, 205-217.

Cui, Y., Parker, G., 2005. Numerical model of sediment pulses and sediment-supply disturbances in mountain rivers. Journal of Hydraulic Engineering 131, 646-656.

Cummins, K.W., Lauff, G.H., 1969. The influence of substrate particle size on the microdistribution of stream macrobenthos. Hydrobiologia 34, 145-181.

DeBano, L.F., 2000. The role of fire and soil heating on water repellency in wildland environments: A review. Journal of Hydrology 231-232, 195-206.

DellaSala, D.A., Williams, J., Deacon Williams, C., Franklin, J.F., 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. Conservation Biology 18, 976-986.

Densmore, R.V., Karle, K.F., 2009. Flood effects on an Alaskan stream restoration project: The value of long-term monitoring. Journal of the American Water Resources Association 45, 1424-1433.

Detenbeck, N.E., DeVore, P.W., Niemi, G.J., Lima, A., 1992. Recovery of temperate-stream fish communities from disturbance: A review of case studies and synthesis of theory. Environmental Management 16, 33-53.

Dettinger, M.D., Cayan, D.R., 1995. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. Journal of Climate 8, 606-623.

Dietrich, W.E., Kirchner, J.W., Ikeda, H., Iseya, F., 1989. Sediment supply and the development of the coarse surface layer in gravel-bedded rivers. Nature 340, 215-217.

Dunbar, J.A., Allen, P.M., Bennett, S.J., 2010. Effect of multiyear drought on upland sediment yield and subsequent impacts on flood control reservoir storage. Water Resources Research 46, WR007519.

Dunham, J.B., Young, M.K., Gresswell, R.E., Rieman B.E., 2003. Effects of fire on fish populations: Landscape perspectives on persistence of native fishes and nonnative fish invasions. Forest Ecology and Management 178, 183-196.

Dunham, J.B., Rosenberger, A.E., Luce, C.H., Rieman, B.E., 2007. Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. Ecosystems 10, 335-346.

Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R., Mearns, L.O., 2000. Climate extremes: Observations, modeling, and impacts. Science 289, 2068-2074.

Easterling, D.R., Wallis, T.W.R., Lawrimore, J.J., Heim Jr., R.R., 2007. Effects of temperature and precipitation trends on U.S. drought. Geophysical Research Letters 34, L20709.

Einstein, H.A., 1968. Deposition of suspended particles in a gravel bed. Journal of Hydraulic Engineering 94, 1197 – 1205.

Everest, F.H., Beschta, R.L., Scrivener, J.C., Koski, K.V., Sedell, J.R., Cederholm, C.J., 1987. Fine sediment and salmonid production: A paradox. In: Salo, E.O., Cundy, T.W. (Eds.), Streamside Management: Forestry and Fishery Interactions. University of Washington Institute of Forest Resources, Seattle, WA, pp. 98-142.

Ferguson, R.I., Bloomer, D.J., Hoey, T.B., Werritty, A., 2002. Mobility of river tracer pebbles over different timescales. Water Resources Research 38, WR000254.

Ferguson, R.I., Cudden, J.R., Hoey, T.B., Rice, S.P., 2006. River system discontinuities due to lateral inputs: Generic styles and controls. Earth Surface Processes and Landforms 31, 1149-1166.

Flannigan, M.D., Krawchuk, M.A., de Goot, W.J., Wotton, B.M., Gowman, L.M., 2009. Implications of changing climate for global wildland fire. International Journal of Wildland Fire 18, 483-507.

Fisher, J.L., Loneragan, W.A., Dixon, K., Delaney, J., Veneklaas, E.J., 2009. Altered vegetation structure and composition linked to fire frequency and plant invasion in a biodiverse woodland. Biological Conservation. 2270-2281.

Florsheim, J.L., Keller, E.A., Best, D., 1991. Fluvial sediment transport in response to moderate storm flows following chaparral wildfire, Ventura County, southern California. Geological Society of America Bulletin 103, 504-511.

Gavin, D.G., Hallett, D.J., Hu, F.S., Lertzman, K.P., Prichard, S.J., Brown, K.J., Lynch, J.A., Bartlein, P., Peterson, D.L., 2007. Forest fire and climate change in western North

America: Insights from sediment charcoal records. Frontiers in Ecology and the Environment 5, 499-506.

Gillett, N.P., Weaver, A.J., Zwiers, F.W., Flannigan, M.D., 2004. Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters 31, L18211.

Gintz, D., Hassan, M.A., Schmidt, K.-H., 1996. Frequency and magnitude of bedload transport in a mountain river. Earth Surface Processes and Landforms 21, 433-445.

Goudie, A.S., 2006. Global warming and fluvial geomorphology. Geomorphology 79, 384-394.

Gray, D.H., Megahan, W.F., 1981. Forest vegetation removal and slope stability in the Idaho Batholith, USDA Forest Service, Intermountain Forest and Range Experiment Station Research Paper INT-271, 23 pp.

Grayson, R.B., Haydon, S.R., Jayasuriya, M.D.A., Finlayson, B.L. 1993. Water quality in mountain ash forests-Separating the impacts of roads from those of logging operations. Journal of Hydrology 150, 459-480.

Greig, S.M., Sear, D.A., Carling, P.A., 2005. The impact of fine sediment accumulation on the survival of incubating salmon progeny: Implications for sediment management. Science of the Total Environment 344, 241-258.

Greig, S.M., Sear, D.A., Carling, P.A., 2007. A review of factors influencing the availability of dissolved oxygen to incubating salmonid embryos. Hydrological Processes 21, 323-334.

Gresswell, S., Heller, D., Swanston, D.N., 1979. Mass movement response to forest management in the central Oregon Coast Ranges, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station Resource Bulletin PNW-84, Portland, OR, 26 pp.

Gucinski, H., Furniss, J., Ziemer, R.R., Brookes, M.H., 2001. Forest roads: A synthesis of scientific information. USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-509, 103 pp.

Hamlet A.F., Lettenmaier, D.P., 1999. Columbia River streamflow forecasting based on ENSO and PDO climate signals. Journal of Water Resources Planning and Management 125, 333-341.

Hamlet, A.F., Lettenmaier, D.P., 2007. Effects of 20th century warming and climate variability on flood risk in the western U.S. Water Resources Research 43, W06427.

Haschenburger, J.K., Church, M., 1998. Bed material transport estimated from the virtual velocity of sediment. Earth Surface Processes and Landforms 23, 791-808.

Hassan, M.A., Church, M., 1992. The movement of individual grains on the streambed. In: Billi, P., Hey, R.D., Thorne, C.R., Tacconi, P. (Eds.), Dynamics of Gravel-bed Rivers. Wiley, Chichester, pp. 159-175.

Haupt, H.F., Kidd, W.J., 1965. Good logging practices reduce sedimentation in central Idaho. Journal of Forestry 63, 664-670.

Hausel, D.A., Coble, D.W., 1976. Influence of sand in redds on survival and emergence of brook trout (*Salvelinus fontinalis*). Transactions of the American Fisheries Society 105, 57-63.

Hereford, R., 2002. Valley-fill alleviation during the Little Ice Age (ca. A.D. 1400-1880), Paria River basin and southern Colorado Plateau, United States. Geological Society of America Bulletin 114, 1550-1563.

Hessburg, P.F., Agee, J.K., 2003. An environmental narrative of Inland Northwest United States forests, 1800-2000. Forest Ecology and Management 178, 23-59.

Heyerdahl, E.K., Morgan, P., Riser II, J.P., 2008. Multi-season climate synchronized historical fires in dry forests (1650-1900), Northern Rockies, USA. Ecology 89, 705-716.

Holden, Z.A., Morgan, P., Crimmins, M.A., Steinhorst, R.K., Smith, A.M.S., 2007. Fire season precipitation variability influences fire extent and severity in a large south-western wilderness area, United States. Geophysical Research Letters 34, L16708.

Hooke, R.L., 2000. Toward a uniform theory of clastic sediment yield in fluvial systems. Geological Society of America Bulletin 112, 1778-1786.

Hughes, M.K., Diaz, H.F., 2008. Climate variability and change in the drylands of western North America. Global Planetary Change 64, 111-118.

Isaak, D.J., Luce, C.H., Rieman, B.E., Nagel, D.E., Peterson, E.E., Horan, D.L., Parkes, S., Chandler, G.L. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. Ecological Applications 20, 1350-1371.

Istanbulluoglu, E., Bras, R.L., 2006. On the dynamics of soil moisture, vegetation, and erosion: Implications for climate variability and change. Water Resources Research 42, W06418.

Istanbulluoglu, E., Tarboton, D.G., Pack, R.T., Luce, C.H., 2002. A probabilistic approach for channel initiation. Water Resources Research 38, 1325.

Istanbulluoglu, E., Tarboton, D.G., Pack, R.T., Luce C.H., 2003. A sediment transport model for incision of gullies on steep topography. Water Resources Research 39, 1103.

Istanbulluoglu, E., Tarboton, D.G., Pack, R.T., Luce C.H., 2004. Modeling of the interactions between forest vegetation, disturbances, and sediment yields. Journal of Geophysical Research–Earth Surface 109, F01009.

Jackson, M., Roering, J.J., 2009. Post-fire geomorphic response in steep, forested landscapes: Oregon Coast Range, USA. Quaternary Science Reviews 28, 1131-1146.

Jain, S., Hoerling, M., Eischeid, J., 2005. Decreasing reliability and increasing synchroneity of western North American streamflow. Journal of Climate 18, 613-618.

James, A., 1991. Incision and morphologic evolution of an alluvial channel recovering from hydraulic mining sediment. Geological Society of America Bulletin 103, 723-736.

James, A., 1999. Time and the persistence of alluvium: River engineering, fluvial geomorphology, and mining sediment in California. Geomorphology 31, 265-290.

Jensen, F., Cole, G.F., 1965. South Fork of the Salmon River storm and flood report. Unpub. report on file at: USDA Forest Service, Payette National Forest, McCall, ID.

Johnson, A.C., Swanston, D.N., McGee, K.E., 2000. Landslide initiation, runout, and deposition within clearcuts and old-growth forests of Alaska. Journal of the American Water Resources Association 36, 17-30.

Jones, J.A., Swanson, F.J., Wemple, B.C., Snyder K.I., 2000. Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14, 76-85.

Kauffman, J.B., Krueger, W.C., 1984. Livestock impacts on riparian ecosystems and streamside management implications … a review. Journal of Range Management 37, 430-438.

Keane, R.E., Arno, S.F., Brown, J.K., 1990. Simulating cumulative fire effects in ponderosa pine/Douglas-fir forests. Ecology 71, 189-203.

Keppeler, E., Lewis, J., Lisle, T., 2003. Effects of forest management on streamflow, sediment yield, and erosion, Caspar Creek experimental watersheds. The First Interagency Conference on Research in the Watersheds. USDA Agricultural Research Service, Washington, DC, pp. 77–82.

Kershner, J.L., Roper, B.B., Bouwes, N., Henderson, R., Archer. E. 2004. An analysis of stream habitat conditions in reference and managed watersheds on some federal lands within the Columbia River Basin. North American Journal of Fisheries Management 24, 1363-1375.

Ketcheson, G.L., Megahan, W.F., 1996. Predicting the downslope travel of granitic sediments from forest roads in Idaho. Journal of American Water Resources Association 32, 371-382.

Ketcheson, G.L., Megahan, W.F., King, J.G., 1999. "R1-R4" and "BOISED" sediment prediction model tests using forest roads in granitics. Journal of the American Water Resources Association 35, 83-98.

King, J.G., 1989. Streamflow responses to road building and harvesting: a comparison with the equivalent clearcut area procedure. USDA Forest Service, Intermountain Research Station, Research Paper INT-401, 13 pp.

King, J.G., Emmett, W.W., Whiting, P.J., Kenworthy, R.P., Barry, J., 2004. Sediment transport data related information for selected coarse-bed streams and rivers in Idaho. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-131, 26 pp.

Kirchner, J.W., Finkel, R.C., Riebe, C.S., Granger, D.E., Clayton, J.L., King, J.G., Megahan W.F., 2001. Mountain erosion over 10 yr., 10 k.y., and 10 m.y. time scales. Geology 29, 591-594.

Kirkby, M.J., Cox, N.J., 1995. A climate index for soil erosion potential (CSEP) including seasonal and vegetation factors. Catena, 25, 333-352.

Kitzberger, T., Brown, P.M., Heyerdahl, E.K., Swetnam, T.W., Veblen, T., 2007. Contingent Pacific-Atlantic Ocean influence on multicentury wildfire synchrony over western North America. Proceedings of the National Academy of Sciences of the USA 104, 543-548.

Klock, G.O., Helvey, J.D., 1976. Debris flows following wildfire in north central Washington. Proceedings of the Third Inter-Agency Sedimentation Conference. US Water Resources Council, Sedimentation Committee, Washington, DC, pp. 1-91 – 1-98.

Knowles, N., Dettinger, M.D., Cayan, D.R., 2006. Trends in snowfall versus rainfall in the western United States. Journal of Climate 19, 4545-4559.

Knox, J.C., 1993. Large increases in flood magnitude in response to modest changes in climate. Nature 361, 430–432.

Kondolf, G.M., Piégay, H., Landon, N., 2002. Channel response to increased and decreased bedload supply from land use change: contrasts between two catchments 45, 35-51.

Lamarre, H., Roy, A.G., 2008. The role of morphology on the displacement of particles in a step-pool river system. Geomorphology 99, 270-279.

Lamb, M.P., Dietrich, W.E., Venditti, J.G., 2008. Is the critical Shields stress for incipient sediment motion dependent on channel-bed slope? Journal of Geophysical Research-Earth Surface 113, F02008.

Lane, S.N., Reid, S.C., Tayefi, V., Yu, D., Hardy, R.J., 2008. Reconceptualising coarse sediment delivery problems in rivers as catchment-scale and diffuse. Geomorphology 98, 227-249.

Langbein, W.B., Schumm, S.A., 1958. Yield of sediment in relation to mean annual precipitation. Transactions, American Geophysical Union 39, 1076-1084.

Lapointe, M.F., Bergeron, N.E., Bérubé, F., Pouliot, M.-A., Johnston, P., 2004. Interactive effects of substrate sand and silt contents, redd-scale hydraulic gradients, and interstitial velocities on egg-to-emergence survival of Atlantic salmon (Salmo salar). Canadian Journal of Fisheries and Aquatic Science 61, 2271-2277.

Lee, D.C., Sedell, J.R., Rieman, B.E., Thurow, R.F., Williams, J.E., Burns, D., Clayton, J.L., Decker, L., Gresswell, R., House, R., Howell, P., Lee, K.M., Macdonald, K., McIntyre, J., McKinney, S., Noel, T., O'Connor, J.E., Overton, C.K., Perkinson, D., Tu K., Van Eimeren, P., 1997. Broadscale assessment of aquatic species and habitats. In: Quigley, T.M., Arbelbiden, S. J. (Eds.), An assessment of ecosystem components in the interior Columbia Basin and portions of the Klamath and Great Basins. USDA Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-405, Vol. III, pp. 1057-1713.

Lenzi, M.A., 2004. Displacement and transport of marked pebbles, cobbles, and boulders during floods in a steep mountain stream. Hydrological Processes 18, 1899-1914.

Leopold, A., 1924. Grass, brush, timber, and fire in southern Arizona. Journal of Forestry 22, 1-10.

Lewicki, M., Buffington, J.M., Thurow, R.F., Isaak, D.J., 2006. Numerical model of channel and aquatic habitat response to sediment pulses in mountain rivers of central Idaho. Eos, Transactions, American Geophysical Union 87, Fall Meeting Supplement, Abstract H51B-0481.

Lisle, T.E., 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water Resources Research 25, 1303-1319.

Lisle, T.E., 2008. The evolution of sediment waves influenced by varying transport capacity in heterogeneous rivers. In: Habersack, H., Piégay, H., Rinaldi, M. (Eds.), Gravel-Bed Rivers VI: From Process Understanding to River Restoration. Elsevier, Amsterdam, pp. 443-472.

Lisle, T.E., Hilton, S., 1992. The volume of fine sediment in pools: An index of sediment supply in gravel-bed streams. Water Resources Bulletin 28, 371-383.

Lisle, T.E., Nelson, J.M., Pitlick, J., Madej, M.A., Barkett, B.L., 2000. Variability of bed mobility in natural, gravel-bed channels and adjustments to sediment load at local and reach scales. Water Resources Research 36, 3743-3755.

Littell, J.S., McKenzie, D. Peterson, D.L., Westerling, A.L., 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003. Ecological Applications 19, 1003-1021.

Luce, C.H., 1997. Effectiveness of road ripping in restoring infiltration capacity of forest roads. Restoration Ecology 5, 265–270.

Luce, C.H., 2002. Hydrological processes and pathways affected by forest roads: What do we still need to learn? Hydrological Processes 16, 2901-2904.

Luce, C.H., Black, T.A., 1999. Sediment production from forest roads in western Oregon. Water Resources Research 35, 2561-2570.

Luce, C.H., Black, T.A., 2001a. Effects of traffic and ditch maintenance on forest road sediment production. In: Proceedings of the Seventh Federal Interagency Sedimentation Conference. US Subcommittee on Sedimentation, Washington, DC, pp. V67–V74.

Luce, C.H., Black, T.A., 2001b. Spatial and temporal patterns in erosion from forest roads. In: Wigmosta, M.S., Burges, S.J., (Eds.), Influence of Urban and Forest Land Uses on the Hydrologic-Geomorphic Responses of Watersheds. American Geophysical Union, Washington, DC, pp. 165-178.

Luce, C.H., Cundy, T.W., 1994. Parameter identification for a runoff model for forest roads. Water Resources Research 30, 1057–1069.

Luce, C.H., Holden Z.A., 2009. Declining annual streamflow distributions in the Pacific Northwest United States, 1948-2006. Geophysical Research Letters, L16401.

Lyon, J.P., O'Connor J.P., 2008. Smoke on the water: Can riverine fish populations recover following a catastrophic fire-related slug? Austral Ecology 33, 794-806.

MacDonald, L.H., Anderson, D.M., Dietrich, W.E., 1997. Paradise threatened: Land use and erosion on St. John, US Virgin Islands. Environmental Management 21, 851–863.

MacDonald, L.H., Sampson, R.W., Anderson, D.M., 2001. Runoff and road erosion at the plot and road segment scales, St John, US Virgin Islands. Earth Surface Processes and Landforms 26, 251-272.

Macklin, M.G., Brewer, P.A., Hudson-Edwards, K.A., Bird, G., Coulthard, T.J., Dennis, I.A., Lechler, P.J., Miller, J.R., Turner, J.N., 2006. A geomorphological approach to the mamagement of rivers contaminated by metal mining. Geomorphology 79, 423-447.

Madej, M.A., 2001, Erosion and sediment delivery following removal of forest roads. Earth Surface Processes and Landforms 26, 175-190.

Madej, M.A., Ozaki, V., 1996. Channel response to sediment wave propagation and movement, Redwood Creek, California, USA. Earth Surface Processes and Landforms 21, 911-927.

Madej, M.A., Ozaki, V. 2009. Persistence of effects of high sediment loading in a salmon-bearing river, northern California. In: James, L.A., Rathburn, S.L. Whittecar, G.R. (Eds.), Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts. Geological Society of America Special Paper 451, pp. 43-55.

Magilligan, F.J., McDowell, P.F., 1997. Stream channel adjustments following elimination of cattle grazing. Journal of the American Water Resources Association 33, 867-878.

Marlon, J., Bartein, P.J., Whitlock C., 2006. Fire – fuel – climate linkages in the northwestern USA during the Holocene. The Holocene 16, 1059-1071.

May, C.L., Pryor, B., Lisle, T.E., Lang, M., 2009. Coupling hydrodynamic modeling and empirical measures of bed mobility to predict the risk of scour and fill of salmon redds in a large regulated river. Water Resources Research 45, W05402.

McAuliffe, J.R., Scuderi, L.A., McFadden, L.D., 2006. Tree-ring record of hillslope erosion and valley floor dynamics: Landscape responses to climate variation during the last 400yr in the Colorado Plateau, northeastern Arizona. Global Planetary Change 50, 184-201.

McCabe , G.J., Palecki, M.A., Betancourt, J.L., 2004. Pacific and Atlantic Ocean influences on multi-decadal drought frequency in the United States. Proceedings of the National Academy of Sciences, USA 101, 4136 – 4141.

McFadden, L.D., McAuliffe, 1997. Lithologically influenced geomorphic responses to Holocene climatic changes in the Southern Plateau, Arizona: A soil-geomorphic and ecologic perspective. Geomorphology 19, 303-332.

McKenzie, D., Gedalof, Z., Peterson, D.L., Mote, P., 2004. Climate change, wildfire, and conservation. Conservation Biology 18, 890-902.

Megahan, W.F., 1974. Erosion over time on severely disturbed granitic soils: A model. USDA Forest Service, Intermountain Research Station, Research Paper INT-156, 14 pp.

Megahan, W.F., 1986. Recent studies on erosion and its control on forest lands in the United States, 18th IUFRO (International Union of Forestry Research Organizations) World Congress, Division 1. pp. 178-189.

Megahan, W.F., Kidd, W.J., 1972. Effects of logging roads on sediment production rates in the Idaho Batholith. USDA Forest Service, Intermountain Research Station, Research Paper INT-123, 14 pp.

Megahan, W.F., Molitor, D.C., 1975. Erosional effects of wildfire and logging in Idaho. In: Symposium on Watershed Management. American Society of Civil Engineers, New York. pp. 423-444.
Megahan, W.F., Day, N.F., Bliss, T.M., 1978. Landslide occurrence in the western and central northern Rocky Mountain physiographic province in Idaho. In: Youngberg, C.T. (Ed.), Forest Soils and Land Use, Proceedings of the Fifth North American Forest Soils Conference. Colorado State University, Department of Forest and Wood Sciences, Fort Collins, CO, pp. 116-139.
Megahan, W.F., Platts, W., Kulesza, B., 1980. Riverbed improves over time: South Fork Salmon. In: Symposium on Watershed Management. American Society of Civil Engineers, New York, pp. 380-395.
Megahan, W.F., Potyondy, J.P., Seyedbagheri, K.A., 1992. Best management practices and cumulative effects from sedimentation in the South Fork Salmon River: An Idaho case study. In: Naiman, R.J. (Ed.), Watershed Management. Springer-Verlag, New York, pp. 401-414.
Megahan, W.F., King, J.G., Seyedbagheri, K.A., 1995. Hydrologic and erosional responses of a granitic watershed to helicopter logging and broadcast burning. Forest Science 41, 777-795.
Megahan, W.F., Wilson, M., Monsen, S.B., 2001. Sediment production from granitic cutslopes on forest roads in Idaho, USA. Earth Surface Processes and Landforms 26, 153-163.
Meyer, G.A., Pierce, J.L., 2003. Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: A long-term perspective. Forest Ecology and Management 178, 89-104.
Meyer, G.A., Wells, S.G., 1997. Fire-related sedimentation events on alluvial fans, Yellowstone National Park, USA. Journal of Sedimentary Research 67, 766-791.
Meyer, G.A., Wells, S.G., Jull, A.J.T., 1995. Fire and alluvial chronology in Yellowstone National Park: Climatic and intrinsic controls on Holocene geomorphic processes. Geological Society of America Bulletin 107, 1211–1230.
Meyer, G.A., Pierce, J.L., Wood, S.H., Jull, A.J.T., 2001. Fire, storms, and erosional events in the Idaho batholith. Hydrological Processes 15, 3025-3038.
Miller, J.P., Leopold, L.B., 1961. Simple Measurements of Morphological Changes in River Channels and Hillslopes, in UNESCO Symposium on Changes of Climate Proceedings, pp. 421-427.
Miller, C., Urban, D.L., 2000, Modeling the effects of forest management alternatives on Sierra Nevada mixed-conifer forests. Ecological Applications 10, 85-94.
Miller, D., Luce, C., Benda, L., 2003. Time, space, and episodicity of physical disturbance in streams. Forest Ecology and Management 178, 121-140.
Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., Stouffer, R.J., 2008. Stationarity is dead: Whither water management? Science 319, 573-574.
Molnar, P., 2001. Climate change, flooding in arid environments, and erosion rates. Geology 29, 1071-1074.
Montgomery, D. R., 1994. Road surface drainage, channel initiation, and slope instability. Water Resources Research, 30, 1925-1932.
Montgomery, D.R., 2003. King of Fish: The Thousand-Year Run of Salmon, Westview Press, Boulder, CO.

Montgomery, D.R., Buffington, J.M., 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109, 596-611.

Montgomery, D.R., Buffington, J.M., Peterson, N.P., Schuett-Hames, D., Quinn, T.P., 1996. Streambed scour, egg burial depths, and the influence of salmonid spawning on bed surface mobility and embryo survival. Canadian Journal of Fisheries and Aquatic Sciences 53, 1061-1070.

Montgomery, D.R., Beamer, E.M., Pess, G.R., Quinn, T.P., 1999. Channel type and salmonid spawning distribution and abundance. Canadian Journal of Fisheries and Aquatic Sciences 56, 377-387.

Montgomery, D.R., Schmidt, K.M., Greenberg, H.M., Dietrich, W.E., 2000. Forest clearing and regional landsliding. Geology 28, 311-314.

Moody, J.A., Martin, D.A., 2009. Synthesis of sediment yields after wildland fire in different rainfall regimes in the western United States. International Journal of Wildland Fire 18, 96-115.

Moody, J.A., Martin, D.A., Cannon, S.H., 2008. Post-wildfire erosion in two geologic terrains in the western USA. Geomorphology 92, 103-118.

Morgan, P., Heyerdahl, E.K., Gibson, C.E., 2008. Multi-season climate synchronized forest fires throughout the 20th century, northern Rockies, USA. Ecology 89, 717-728.

Mote, P.W., Hamlet, A.F., Clark, M.P., Lettenmaier, D.P., 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society 86, 1-39.

Motha, J.A., Wallbrink, P.J., Hairsine, P.B., Grayson, R.B., 2003. Determining the sources of suspended sediment in a forested catchment in south-eastern Australia. Water Resources Research 39, 1056.

Nehlsen, W., Williams, J.E., Lichatowich, J.A., 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16, 4-21.

Nelson, R.L., McHenry, M.L., Platts, W.S., 1991. Mining. In: Meehan, W.R. (Ed.), Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19, Bethesda, MD, pp. 425-457.

Overpeck, J.T., Udall, B., 2010. Dry times ahead. Science 328, 1642-1643.

Overpeck, J.T., Rind, D., Goldberg, R., 1990. Climate-induced changes in forest disturbance and vegetation. Nature 343, 51-53.

Pagano, T., Garen, D., 2005. A recent increase in Western U.S. streamflow variability and persistence. Journal of Hydrometeorology 6, 173-179.

Peterson, J.H., Kitchell, J.F., 2001. Climate regimes and water temperature changes in the Columbia River: Bioenergetic implications for predators of juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 58, 1831-1841.

Pierce, J.L., Meyer, G.A., 2008. Long-term history from alluvial fan sediments: The role of drought and climate variability, and implications for management of Rocky Mountain forests. International Journal of Wildland Fire 17, 84-95.

Pierce, J.L., Meyer, G.A., Jull, A.J.T., 2004. Fire-induced erosion and millennial scale climate change in northern ponderosa pine forests. Nature 432, 87-90.

Pierce, J.L., Meyer, G.A., Rittenour, T., 2011. The relation of Holocene fluvial terraces to changes in climate and sediment supply, South Fork Payette River, Idaho. Quaternary Science Reviews 30, 628-645.

Pitlick, J., 1994. Relation between peak flows, precipitation, and physiography for five mountain regions in the western US. Journal of Hydrology 158, 219-240.

Platts, W.S., 1991. Livestock grazing. In: Meehan, W.R. (Ed.), Influences of Forest and Rangeland Management on Salmnoid Fishes and Their Habitats. American Fisheries Society Special Publication 19, Bethesda, MD, pp. 389-423.

Prasad, A. 2007. A tool to analyze environmental impacts of roads on forested watersheds. Unpub. M.S. Thesis. Utah State University, Logan, 211 pp.

Rajagopalan, B., Nowak, K., Prairie, J., Hoerling, M., Harding, B., Barsugli, J., Ray, A., Udall B., 2009. Water supply risk on the Colorado River: Can management mitigate? Water Resources Research 45, W08201, doi:10.1029/2008WR007652.

Reeves, G., Benda, L., Burnett, K., Bisson, P., Sedell, J., 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionary significant units of anadromous salmonids in the Pacific Northwest. In: Nielsen, J.L. (Ed.), Evolution and the Aquatic Ecosystem: Defining Unique Units in Population Conservation. American Fisheries Society Symposium 17, Bethesda, MD, pp. 334–349.

Regonda, S., Rajagopalan, B., Clark, M., Pitlick J., 2005. Seasonal cycle shifts in hydroclimatology over the western United States. Journal of Climate 18, 372–384. doi:10.1175/JCLI-3272.1.

Reid, L.M., Dunne, T., 1984. Sediment production from forest road surfaces. Water Resources Research 20, 1753-1761.

Reid, L.M., Dunne, T., Cederholm, C.J., 1981. Application of sediment budget studies to the evaluation of logging road impact. New Zealand Journal of Hydrology 20, 49-62.

Resh, V.H., Brown, A.V., Covich, A.P., Gurtz, M.E., Li, H.W., Minshall, G.W., Reice, S.R., Sheldon, A.L., Wallace, J.B., Wissman, R.C., 1988. The role of disturbance in stream ecology. North American Benthological Society 7, 433–455.

Rice, R.M., Corbett, E.S., Bailey, R.G., 1969. Soil slips related to vegetation, topography, and soil in southern California. Water Resources Research 5, 647-659.

Rice, S.P., Greenwood, M.T., Joyce, C.B., 2001. Macroinvertebrate community changes at coarse sediment recruitment points along two gravel bed rivers. Water Resources Research 37, 2793-2803.

Rieman B.E., Lee D.C., Chandler G., Myers D., 1997. Does wildfire threaten extinction for salmonids? Responses of redband trout and bull trout following recent large fires on the Boise National Forest. In: Greenlee J. (Ed.), Proceedings of the Conference on Wildfire and Threatened and Endangered Species and Habitats. International Association of Wildland Fire, Fairfield, WA, pp 47–57.

Rieman, B.E., Hessburg, P.F., Luce, C., Dare, M.R., 2010. Wildfire and management of forests and native fishes: Conflict or opportunity for convergent solutions? BioScience 60, 460-468.

Robichaud, P.R., Beyers, J.L., Neary, D.G., 2000. Evaluating the effectiveness of postfire rehabilitation treatments. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-63, 85 pp.

Roering, J.J., Gerber, M., 2005. Fire and the evolution of steep, soil-mantled landscapes. Geology 33, 349-352.

Rosenberger, A., Dunham, J., Rieman, B., 2005. Effects of wildfire and channel disturbance on individual and life-history traits of rainbow trout in Idaho streams. American Fisheries Society Annual Meeting, Anchorage, AK, http://209.66.94.27/2005Abs/afssearchinfo_sched.cfm.

Rosenberger, A.E., Dunham, J.B., Buffington, J.M., Wipfli, M.S., 2011. Persistent effects of wildfire and debris flows on the invertebrate prey base of rainbow trout in Idaho streams. Northwest Science 85, 55-63.

Ryan, S.E., Dixon, M.K., 2008. Spatial and temporal variability in stream sediment loads using examples from the Gros Ventre Range, Wyoming, USA. In: Habersack, H., Piégay, H., Rinaldi, M. (Eds.), Gravel-Bed Rivers VI: From Process Understanding to River Restoration. Elsevier, Amsterdam, pp. 387-407.

Salo, E.O., Cundy, T.W. (Eds.), 1987. Streamside Management: Forestry and Fishery Interactions. University of Washington, Institute of Forest Resources, Seattle, WA, 471 pp.

Schmidt, K.M., Roering, J.J., Stock, J.D., Dietrich, W.E., Montgomery, D.R., Schaub, T., 2001. The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range. Canadian Geotechnical Journal 38, 995-1024.

Schmidt, K.M., Menakis, J.P., Hardy, C.C., Hann, W.J., Bunnell, D.L. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS GTR-87, 41 pp.

Schumm, S.A., Hadley, R.F., 1957. Arroyos and the semiarid cycle of erosion. American Journal of Science 255, 164-174

Schumm, S.A., Parker, R.S., 1973. Implications for complex response of drainage systems for Quaternary alluvial stratigraphy. Nature 243, 99-100.

Service, R.F., 2004. As the West goes dry. Science 303, 1124-1127.

Seyedbagheri, K.A., McHenry, M.L., Platts, W.S., 1987. An annotated bibliography of the hydrology and fishery studies of the South Fork Salmon River. USDA Forest Service, Intermountain Research Station, General Technical Report INT-235, 27 pp.

Shakesby, R.A., Doerr, S.H., 2006. Wildfire as a hydrological and geomorphological agent. Earth Science Reviews 74, 269-307.

Shaub, S., 2001. Landslides and wildfire: An example from the Boise National Forest. unpub. M.S. thesis, Boise State University, Boise, ID, 85 pp.

Sidle, R.C., 2005. Influence of forest harvesting activities on debris avalanches and flows. In: Jakob, M., Hungr, O. (Eds.), Debris Flow Hazards and Related Phenomena. Springer-Praxis, Heidelberg, pp. 345-367.

Sidle, R.C., Pearce, A.J., O'Loughlin, C.L., 1986. Hillslope stability and land use. Water Resources Monograph 11, American Geophysical Union, Washington, DC, 140 pp.

Smith, J.D., 2004. The role of riparian shrubs in preventing floodplain unraveling along the Clark Fork of the Columbia River in the Deer Lodge Valley, Montana. In: Bennett, S.J., Simon, A. (Eds.), Riparian Vegetation and Fluvial Geomorphology. American Geophysical Union, Washington, DC, pp. 71-85.

Stephens, S.L., Moghaddas, J.J., 2005. Fuel treatment effects on snags and coarse woody debris in a Sierra Nevada mixed conifer forest. Forest Ecology and Management 214, 53-64.

Stewart, I.T., 2009. Changes in snowpack and snowmelt runoff for key mountain regions. Hydrological Processes 23, 78-94.

Stewart, I.T., Cayan, D.R., Dettinger, M.D., 2004. Changes in snowmelt runoff timing in western North America under a "business as usual" climate change scenario. Climatic Change 62, 217-232.

Sutherland, D.G., Hansler-Ball, M.E., Hilton, S.J., Lisle, T.E., 2002. Evolution of a landslide-induced sediment wave in the Navarro River, California. Geological Society of America Bulletin 114, 1036-1048.

Suttle, K.B., Power, M.E., Levine, J.M., McNeely, C., 2004. How fine sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14, 969-974.

Swanson, F.J., 1981. Fire and geomorphic processes. In: Mooney, H.A., Bonnicksen, T.M., Christensen, N.L., Lotan, J.E., Reiners, W.A. (Eds.), Proceedings of the Conference on Fire Regimes and Ecosystem Properties. USDA Forest Service General Technical Report WO-26, pp. 401-420.

Swanson, F.J., Benda, L.E., Duncan, S.H., Grant, G.E., Megahan, W.F., Reid, L.M., Ziemer, R.R., 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. In: Salo, E.O., Cundy, T.W. (Eds.), Streamside Management: Forestry and Fishery Interactions. University of Washington, Institute of Forest Resources, Seattle, WA, pp. 9-38.

Swanston, D.N., 1970. Mechanics of debris flow avalanching in shallow till soils of southeast Alaska, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station Research Paper PNW-103, Portland, OR, 17 pp.

Swanston, D.N., 1971. Principal soil movement processes influenced by road building, logging, and fire. In: Forest Land Uses and Stream Environment. Oregon State University, School of Forestry and Department of Fisheries and Wildlife, Corvallis, OR, pp. 29-40.

Swanston, D.N., 1974. The forest ecosystem of southeast Alaska: 5. Soil mass movement, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station General Technical Report PNW-17, Portland, OR, 22 pp.

Swanston, D.N., 1976. Erosion processes and control methods in North America, 16th IUFRO (International Union of Forestry Research Organizations) World Congress, Division 1. Norwegian Forest Research Institute, Ås, Norway, pp. 251-275.

Swetnam T.W., 1993. Fire history and climate change in giant sequoia groves. Science 262, 885-889.

Swetnam T.W., Betancourt J.L., 1990. Fire–Southern Oscillation relations in the southwestern United States. Science 249, 1017-1020.

Swetnam T.W., Betancourt J.L., 1998. Mesoscale disturbance and ecological response to decadal climate variability in the American Southwest. Journal of Climate 11, 3128-3147.

Switalski, T.A., Bissonette, J.A. DeLuca, T.H., Madej, M.A., 2004. Benefits and impacts of road removal. Frontiers in Ecology and The Environment 2, 21–28.

Tennant, C., Crosby, B.T., 2009. Distinct regimes: The hydrology and geomorphology of twelve tributaries to the Salmon River. Geological Society of America Abstracts with Programs 41(7), 289.

Tonina, D., Buffington, J.M., 2009. A three-dimensional model for analyzing the effects of salmon redds on hyporheic exchange and egg-pocket habitat. Canadian Journal of Fisheries and Aquatic Sciences 66, 2157-2173.

Trimble, S.W., Mendel, A.C., 1995. The cow as a geomorphic agent – A critical review. Geomorphology 13, 233-255.

Trouet, V., Taylor, A.H., Wahl, E.R., Skinner, C.N., Stephens, S.L., 2010. Fire-climate interactions in the American West since 1400 CE. Geophysical Research Letters 37, L04702.

van Mantgem, P.J., Stephenson, N.L., Bryne, J.C., Daniels, L.D., Franklin, J.F., Fulé, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H., Veblen, T.T., 2009. Widespread increase of tree mortality rates in the western United States. Science 323, 521-524.

Verhaar, P. M., Biron, P.M., Ferguson, R.I., Hoey, T.B., 2010. Implications of climate change in the 21st century on simulated magnitude and frequency of bed-material transport in tributaries of the Saint-Lawrence. Hydrological Processes, published online doi: 10.1002/hyp.7918

Webb, B.W., Hannah, D.M., Moore, R.D., Brown, L.E., Nobilis, F., 2008. Recent advances in stream and river temperature research. Hydrological Processes 22, 902-918.

Welcker, C., 2011. Bulking debris flow initiation and impacts. unpub. doctoral dissertation, University of Idaho, Boise, ID, 179 pp.

Wells II, W.G., 1987. The effect of fire on the generation of debris flows. In: Costa, J.E., Wieczorek, G.F. (Eds). Debris flows/avalanches, Geological Society of America Reviews in Engineering Geology 7, pp. 105–114.

Wemple, B.C., Jones, J.A., 2003. Runoff production on forest roads in a steep, mountain catchment. Water Resources Research 39, 1220, doi:10.1029/2002WR001744.

Wemple, B.C., Swanson, F.J., Jones, J.A., 2001. Forest roads and geomorphic process interactions, Cascade range, Oregon. Earth Surface Processes and Landforms 26, 191-204.

Westerling, A.L., Brown, T.J., Gershunov, A., Cayan, D.R., Dettinger, M.D., 2003. Climate and wildfire in the western United States. Bulletin of the American Meteorological Society 84, 595-604.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., Swetnam, T.W., 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313, 940-943.Whiting, P.J., Matisoff, G., Fornes, W., Soster, F.M., 2005. Suspended sediment sources and transport distances in the Yellowstone River basin. Geological Society of America Bulletin 117, 515-529.

Whitlock, C., Bartlein, P.J., 1993. Spatial variations of Holocene climatic change in the Yellowstone region. Quaternary Research 39, 231–238.

Whitlock, C., Bartlein, P.J., 1997. Vegetation and climate change in northwestern America during the past 125 kyr. Nature 388, 57-61.

Whitlock, C., Shafer, S.L., Marlon J., 2003. The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management. Forest Ecology and Management 178, 5-21.

Whitlock, C., Marlon, J., Briles, C., Brunelle, A., Long, C., Bartlein, P., 2008. Long-term relations among fire, fuel, and climate in the north-western US based on lake-sediment studies. International Journal of Wildland Fire 17, 72-83.

Wilcock, P.R., 1992. Flow competence: A criticism of a classic concept. Earth Surface Processes and Landforms 17, 289-298.

Wilcock, P.R., 1998. Two-fraction model of initial sediment motion in gravel-bed rivers. Science 280, 410-412.

Wooster, J.K., Dusterhoff, S.R., Cui, Y., Sklar, L.S., Dietrich, W.E., Malko, M., 2008. Sediment supply and relative size distribution effects on fine sediment infiltration into immobile gravels. Water Resources Research 44, W03424.

Wohl, E., Cenderelli, D.A., 2000. Sediment deposition and transport patterns following a reservoir sediment release. Water Resources Research 36, 319-333.

Zhang, P., Molnar, P., Downs, W.R., 2001. Increased sedimentation rates and grain sizes 2-4 myr ago due to the influence of climate change on erosion rates. Nature 410, 891-897.

Ziegler, A.D., Giambelluca, T.W., 1997. Importance of rural roads as source areas for runoff in mountainous areas of northern Thailand. Journal of Hydrology 196, 204-229.

Ziegler, A.D., Sutherland, R.A., Giambelluca, T.W., 2000. Runoff generation and sediment production on unpaved roads, footpaths, and agricultural land surfaces in northern Thailand. Earth Surface Processes and Landforms 25, 519–534.

Ziemer, R.R., 1981. The role of vegetation in the stability of forested slopes, 17th IUFRO (International Union of Forest Research Organizations) World Congress, Division 1. pp. 297-308.

Figure 1. Conceptual plot of sediment yield (solid line) relative to hydroclimate and the regulating role of vegetation. Sediment yield curve is based on the empirical relationship developed by Langbein and Schumm (1958). The dashed lines indicate the relative increase in resistance to erosion that vegetation provides as the driving force of precipitation increases. The greatest divergence in the lines occurs in semi-arid climates, where there is sufficient precipitation to drive erosion, but a limited amount of frequently-disturbed vegetation to stabilize hillslopes from erosion. The result is greater sediment yield in semi-arid climates.

Figure 2. Lower Snake River study area. Panel A. shows major rivers, four Lower Snake dams, area contributing sediment to these reservoirs, recent fire perimeters (2001-2008), and designated wilderness and roadless areas. The Payette River and Boise River, where many post fire and road sediment studies have been performed, are also shown. Panel B. shows boundaries of the Salmon and Clearwater basins and dominant rock types.

Figure 3. Conceptual pathways for climate-driven changes to sediment yield. The cumulative effect of climate-driven changes in hydrology and wildfire characteristics (frequency, severity, and area burned), leads to greater potential for sediment delivery throughout the year via two mechanisms of post-fire debris flow generation (runoff- vs. saturation-initiated debris flows).

Figure 4. Relative differences in sediment yield for individual post-fire erosional events, long-term basin averages, short-term basin averages, and road-surface erosion. Individual post-fire erosional events include debris flows (Meyer et al., 2001) and gully erosion from the North Fork Boise River (Istanbulluoglu et al., 2003) and debris flows in the Middle Fork Boise River (MFBR, field estimates (Boise National Forest, 2004) and predictions (Cannon et al., 2010)). Long-term basin averages are from cosmogenic analysis of fluvial sediments (Kirchner et al., 2001). Short-term averages for small basins (< 20 km^2) are from catchbasin dams (1950's-1980's; Kirchner et al., 2001) and are subdivided by the presence or absence of roads. Short-term averages for larger basins are predicted from sediment rating curves and daily stream flows (1920-2000; Kirchner et al. 2001), supplemented with data from King et al. (2004) using the same methods and period of record as that of Kirchner et al. (2001). Basin-average road-surface erosion is predicted from GRAIP (Black et al., 2010), with values updated from Prasad (2007) based on measurements of road-surface erosion from the Middle Fork Payette watershed (Black, unpub. data). Event-based road-surface erosion values are from observed, post-construction erosion (4-year average yield, Ketcheson et al., 1999).

Figure 5. Spatial distribution of bankfull competence (median grain size (D_{50}) that can be moved as bed load by bankfull flow) within the Middle Fork Salmon River, central Idaho. Competent grain size is determined from the Shields equation: $D_{50}=\rho ghS/[(\rho_s-\rho)g\tau^*_{c50}]$, where ρ and ρ_s are fluid and sediment densities, respectively, g is gravitational acceleration, h is bankfull flow depth, S is channel slope, and τ^*_{c50} is the critical Shields stress for motion of D_{50}, defined according to Lamb et al. (2008) as $\tau^*_{c50}=0.15S^{0.25}$. Circled reaches are long-term bed load storage zones (low-gradient, unconfined channels with relatively low competence). The overall lack of mid-network storage zones indicates that bed load transport through this sub-basin is relatively fast and efficient.

Figure 6. Predicted values of bed load transport capacity relative to sediment supply for current conditions in gravel- and cobble-bed rivers of central Idaho, spanning a broad range of drainage

areas (16-16,154 km^2). Data from Barry et al. (2004), with sediment supply assumed equal to the observed transport rate for the current 2-year discharge (Q_2). Transport capacity predicted from site-specific bed load rating curves expressed as a function of Dietrich et al.'s (1989) q^* (dimensionless index of transport capacity relative to sediment supply; $q_b=\alpha Q_2^{\beta}=1.01\cdot10^{-9}e^{(17.26q^*)}Q_2^{(3.54-2.33q^*)}$, where q_b is unit bed load transport rate (kg m^{-1} s^{-1}), and α and β are empirical regression parameters), with q^* set equal to 1 (maximum theoretical transport capacity; Dietrich et al., 1989).

Figure 7. Spatial coverage of roads and burned areas in the South Fork Salmon River watershed.

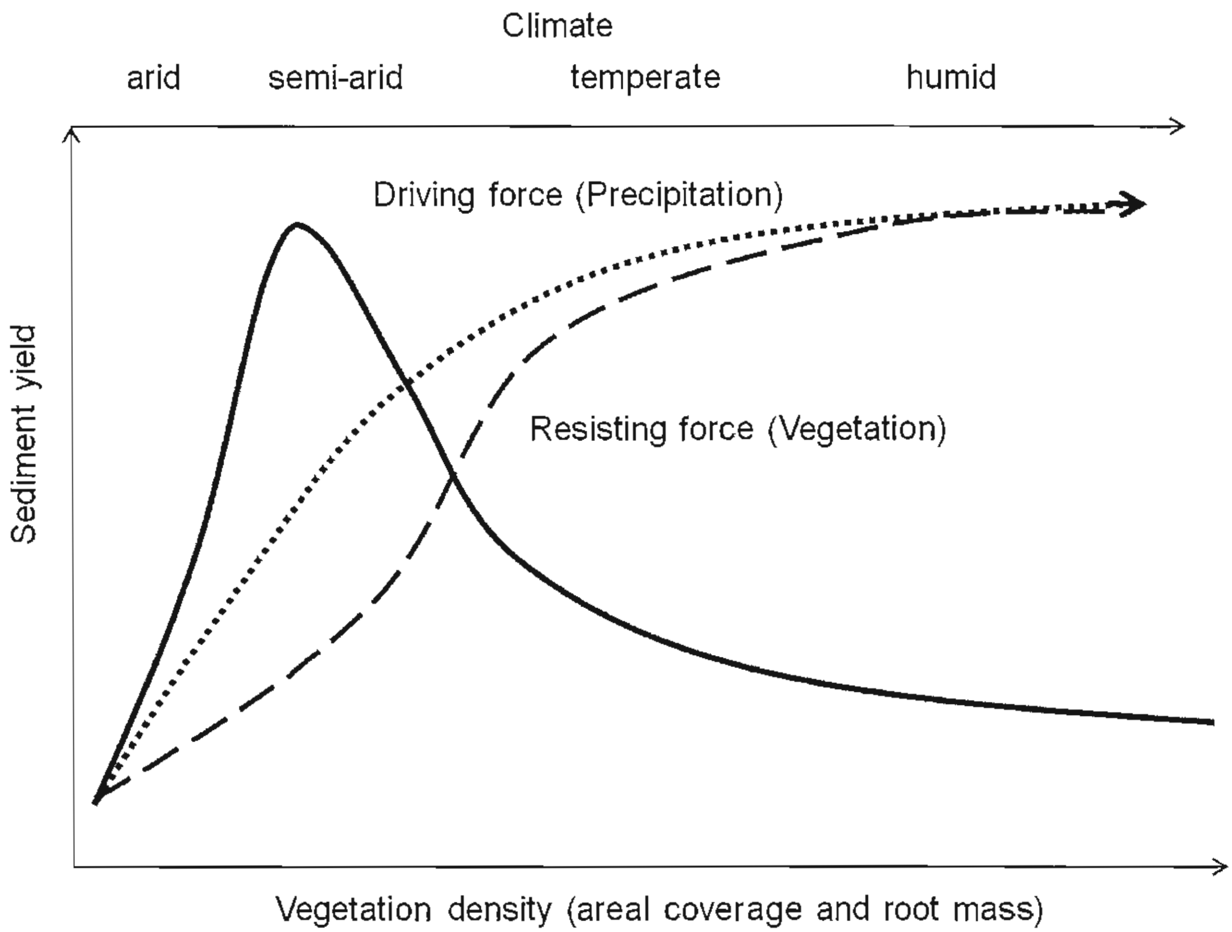

Climate
arid
semi-arid
temperate
humid
Driving force (Precipitation)
Resisting force (Vegetation)
Sediment yield
Vegetation density (areal coverage and root mass)

Figure 1.

Revised Figure 2

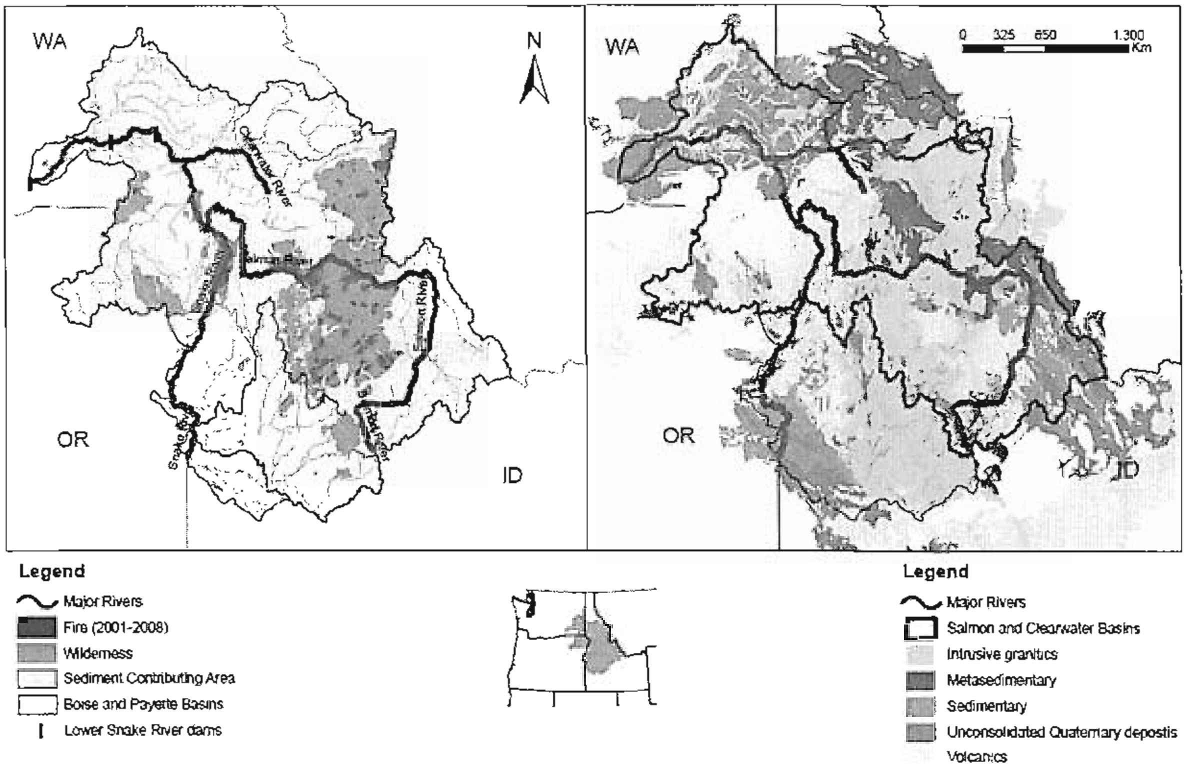


Figure 2.

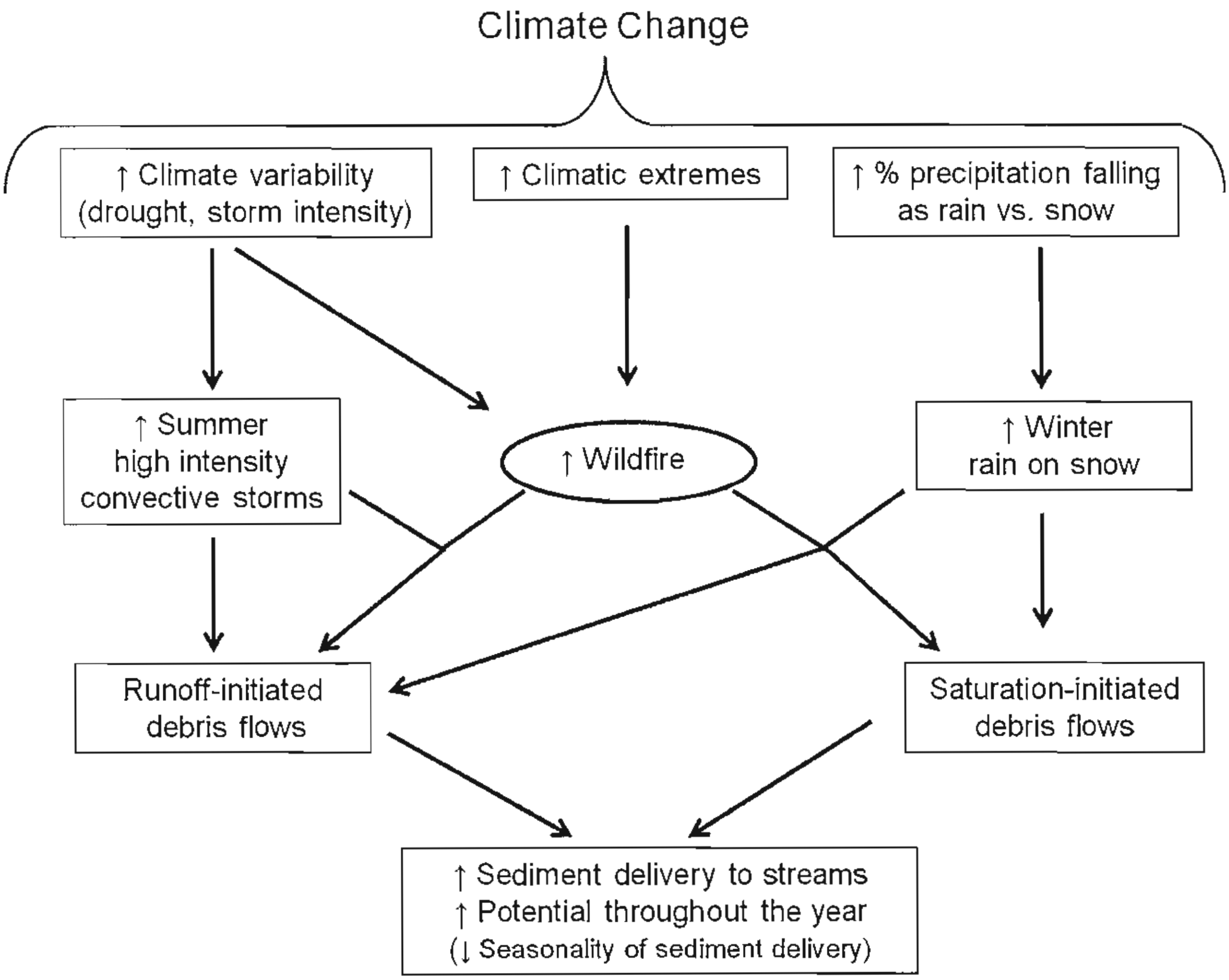

Climate Change
↑ Climate variability (drought, storm intensity)
↑ Climatic extremes
↑ % precipitation falling as rain vs. snow
↑ Summer high intensity convective storms
↑ Wildfire
↑ Winter rain on snow
Runoff-initiated debris flows
Saturation-initiated debris flows
↑ Sediment delivery to streams
↑ Potential throughout the year
(↓ Seasonality of sediment delivery)

Figure 3.

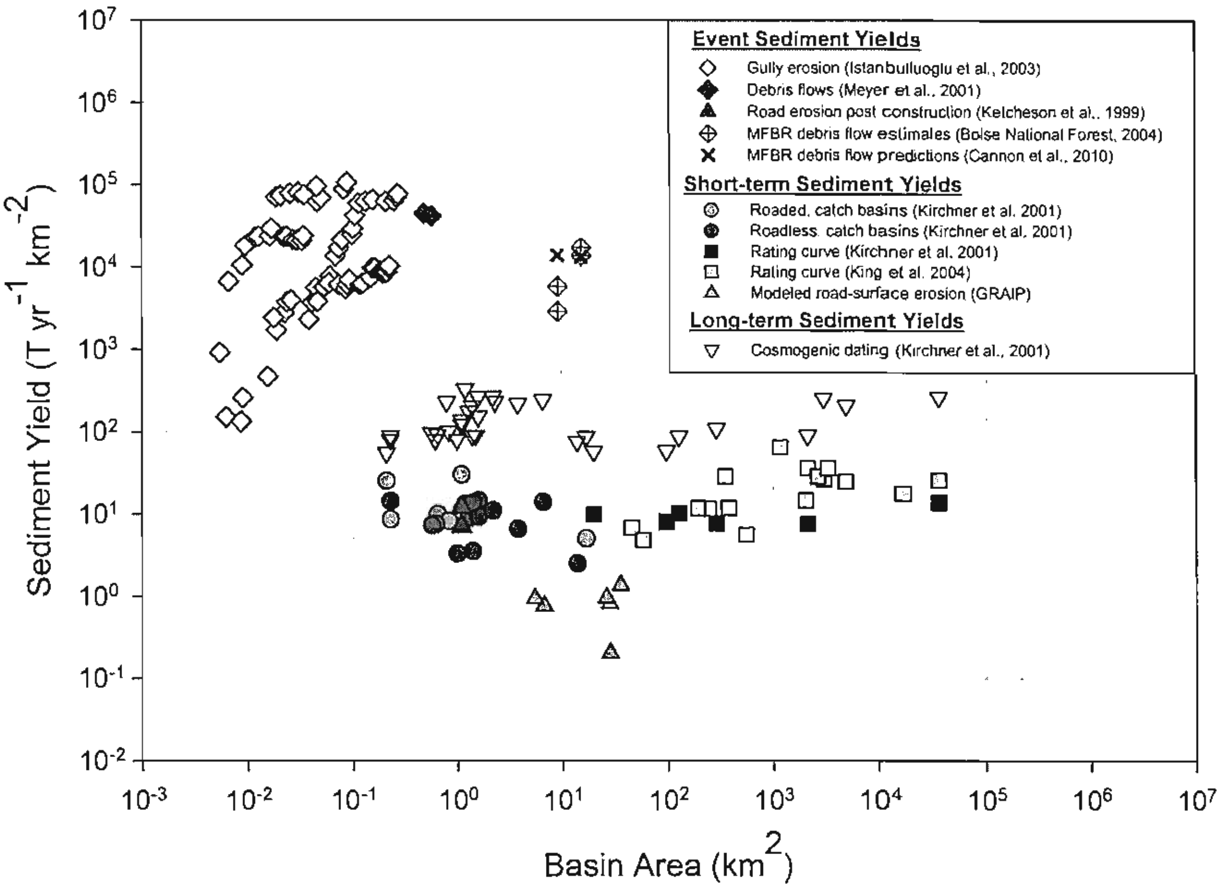

Event Sediment Yields
Gully erosion (Istanbulluoglu et al., 2003)
Debris flows (Meyer et al., 2001)
Road erosion post construction (Ketcheson et al., 1999)
MFBR debris flow estimates (Boise National Forest, 2004)
MFBR debris flow predictions (Cannon et al., 2010)
Short-term Sediment Yields
Roaded, catch basins (Kirchner et al. 2001)
Roadless catch basins (Kirchner et al. 2001)
Rating curve (Kirchner et al. 2001)
Rating curve (King et al. 2004)
Modeled road-surface erosion (GRAIP)
Long-term Sediment Yields
Cosmogenic dating (Kirchner et al., 2001)
Sediment Yield (T yr^{-1} km^{-2})
Basin Area (km^2)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
10^{6}
10^{7}

Figure 4.

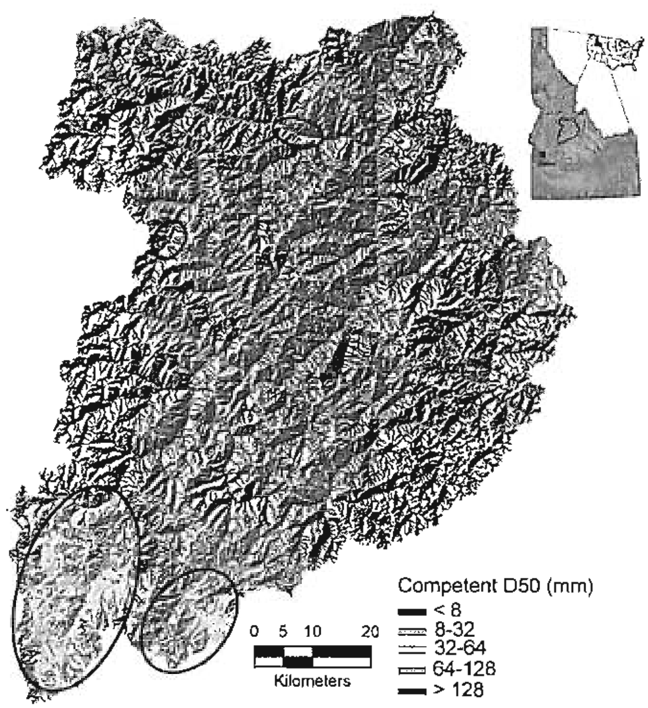
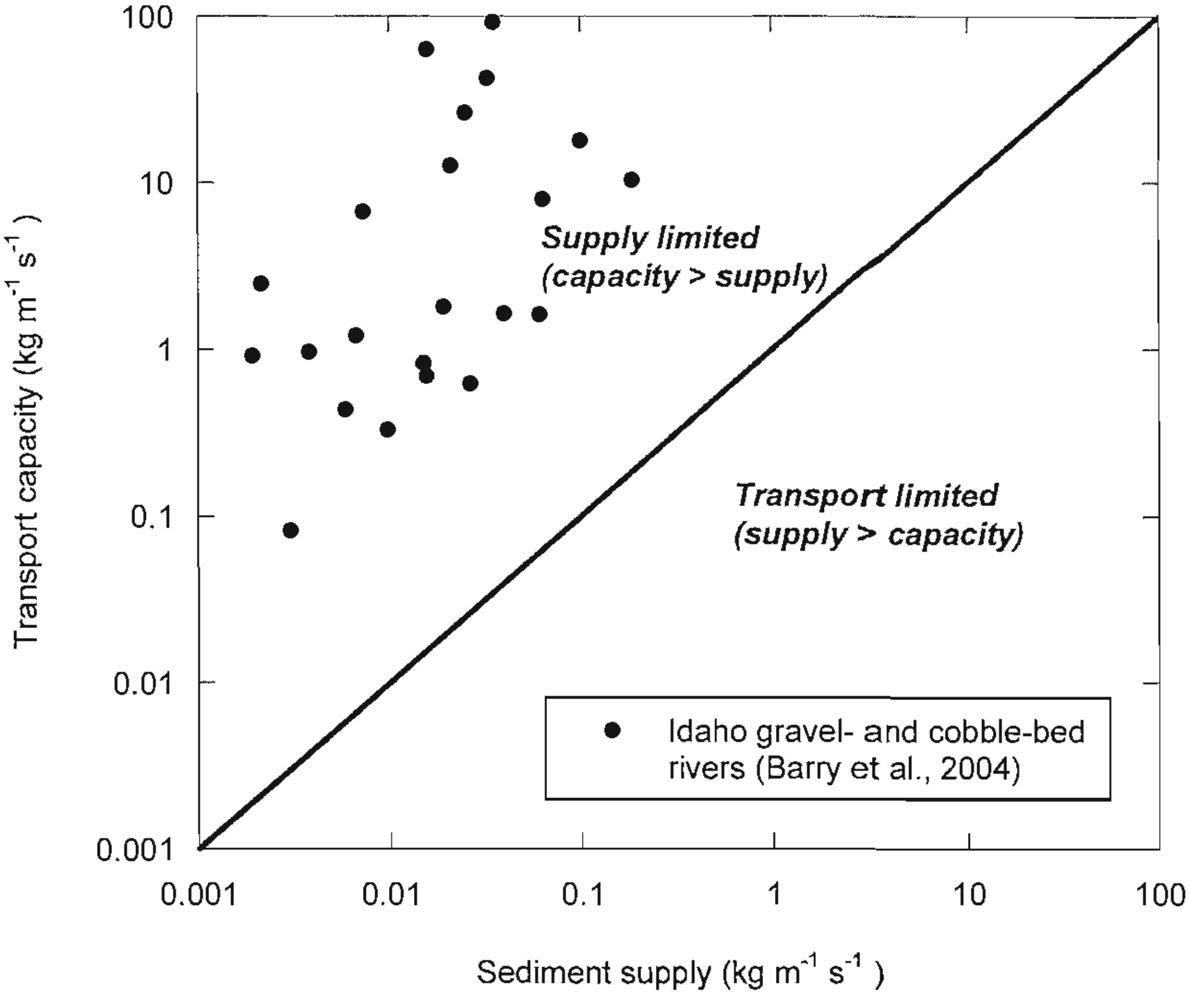


Figure 5.



100
10
1
0.1
0.01
0.001
Transport capacity (kg m-1 s-1)
0.001
0.01
0.1
1
10
100
Sediment supply (kg m-1 s-1)
Supply limited
(capacity > supply)
Transport limited
(supply > capacity)
Idaho gravel- and cobble-bed rivers (Barry et al., 2004)

Figure 6.

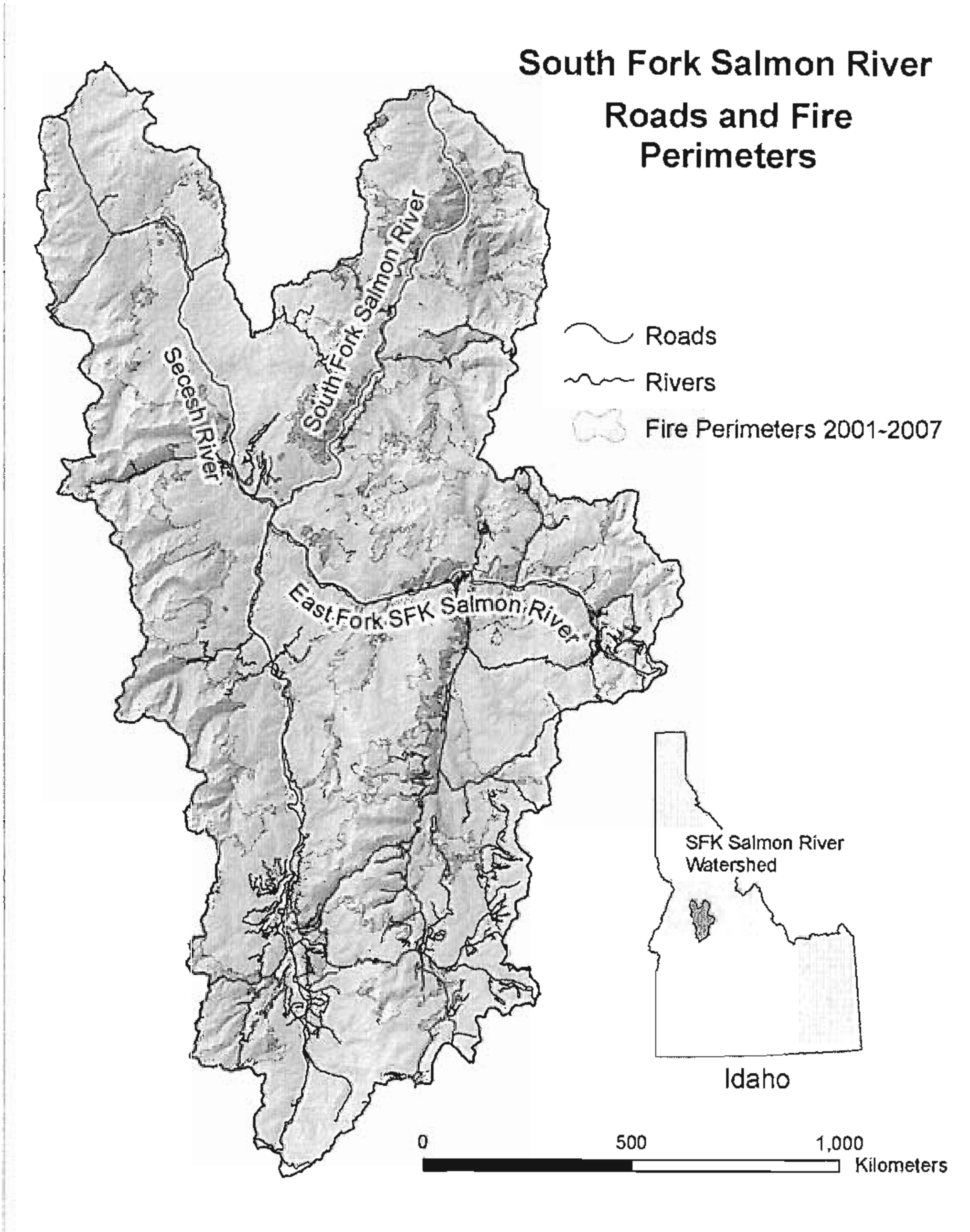

South Fork Salmon River
Roads and Fire Perimeters
Roads
Rivers
Fire Perimeters 2001-2007
South Fork Salmon River
Secesh River
East Fork SFK Salmon River
SFK Salmon River Watershed
Idaho
0
500
1,000
Kilometers

Figure 7

Highlights for: "Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains"

- We expect sediment yield to increase in a changing climate through vegetation disturbances. > In central Idaho, basin-scale sediment yields could be greater than the long-term average rate. > Elevated sediment yields will likely impact downstream reservoirs. > Episodic erosional events that dominate post-fire sediment yields are impractical to mitigate. > Road restoration would provide a relatively minor reduction in sediment loads at the basin-scale.

Appendix E: Evaluation of Sediment Yield Reduction Potential in Agricultural and Mixed-Use Watersheds of the Lower Snake River Basin

Prepared by the University of Idaho and Washington State University, 2010

Evaluation of Sediment Yield Reduction Potential in Agricultural and Mixed-Use Watersheds of the Lower Snake River Basin

Submitted to:

US Army Corps of Engineers
Programmatic Sediment Management Plan (PSMP)
Walla Walla, Washington

Submitted by:

University of Idaho
Moscow, Idaho 83844-2060

Dr. Jan Boll, Biological and Agricultural Engineering
Dr. Erin Brooks, Biological and Agricultural Engineering
Ms. Jane McAtty, Water Resources Program
and

State of Washington Water Research Center
Washington State University
Pullman, Washington 99164-3002

Dr. Michael Barber, State of Washington Water Research Center
Dr. Jeffery Ullman, Biological Systems Engineering
Dr. Don McCool, Agricultural Research Service
Dr. Xiaoqiao Lu, Biological Systems Engineering
Ms. Amanda Lawler, Civil and Environmental Engineering
Mr. Josh Ryan, Civil and Environmental Engineering

DRAFT Date – November 24, 2010

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1.0 Introduction

Despite being extensively studied since the 1930's (Eakin and Brown 1939), reservoir sedimentation continues to be a serious problem in many parts of the world including the United States (Fan and Morris 1992; Dunbar et al. 1999). Nationwide, a study by Crowder (1987) indicated that 0.22% of the nation's water storage capacity is lost annually to sediment damages. Of this amount, an average of 24% of the lost volume is due to soil erosion from cropland although a considerable amount of regional variation existed in the data. The total annual cost of erosion and sedimentation in the United States was estimated to be approximately $44 billion back in 1995 (Pimentel et al. 1995). Problems associated with reservoir sedimentation include loss of several important functions including flood control capacity, firm yield, port and transportation utility, and aquatic habitat. All reservoirs exhibit some effects of sedimentation (Morris and Fan 1998) however excessive upstream sedimentation can significantly reduce the design life of downstream reservoirs or require increased frequencies of maintenance practices such as dredging (Vanoni 2006).

A number of studies have attempted to assess the economic impacts of controlling erosion (Crowder 1987; Enters 1998). Palmieri et al. (2001) proposed a framework for assessing the economic feasibility of sediment management strategies which permitted the life of dams to be prolonged indefinitely. Hansen and Hellerstein (2007) found that for 2,111 U.S. watersheds, a one-ton reduction in soil erosion provided benefits ranging from $0 to $1.38. Using the Hydrologic Simulation Program-Fortran (HSPF) model, Moltz et al. (2010) examined six BMP scenarios for sediment control in a New Mexico watershed. Ranging in cost from $1M to over $66M, they found that sediment loss measured at the basin outlet could be reduced by 3,785 to 4,522 tons/year.

Since agricultural activities are often linked to excessive erosion rates, many studies have focused on cost-effective reduction strategies in rural watersheds. For example, in the early 1980's, a USDA study estimated that many wheat growing areas in the Snake/Clearwater had erosion rates in excess of 25 tons/ha/year (Lee 1984) so agricultural best management practices (BMPs) could effectively be used to reduce soil loss. A key to this is the measurement or prediction of sediment yield versus soil loss. Large quantitative differences may exist between upland soil erosion and downstream sediment delivery (Trimble and Crosson, 2000). Upland erosion may be deposited at other locations in the field, along fencerows, or along streams as alluvium never reaching the water course. Determining the sediment delivery ratio at the watershed scale remains a challenging area of erosion research (Vente et al. 2007).

Reservoir sedimentation is a reoccurring phenomenon near the confluence of the Snake and Clearwater Rivers at the Idaho/Washington state line. The US Army Corps of Engineers (USACE) is authorized by Congress to maintain the federal navigation channel near the Port of Lewiston, Idaho to a width of 250-feet and a depth of 14-feet. Because upstream sediment settles near the confluence of the two streams, the USACE must periodically dredge the navigation channel and the Ports of Lewiston and Clarkston. One possible alternative for reducing the frequency of dredging is to reduce or eliminate upstream sources of sediment in the basin. These sources include those from forests, rangeland, roads, agriculture, urbanization, landslides, and stream banks (TetraTech 2008). As illustrated in Figure 1, assuming the Hells Canyon Dam complex on the Snake River mainstem and Dworshak Reservoir on the North Fork of the Clearwater effectively trap upstream sediments, the area of concern would be approximately 32,000 square miles. Moreover, since approximately 14 percent of the area (4,400 sq. mi.) is classified as agricultural lands (see Figure 2) and agricultural lands are often tied to erosion sources, a detailed investigation of agricultural erosion and yield is warranted.

The overall purpose of this work is to assess the current sediment yield and the feasibility of sediment reduction measures in agricultural and mixed-use watersheds of the Lower Snake River Basin. The assessment data and findings will support development of the Programmatic Sediment Management Plan. Specific objectives are to:

- Review and summarize existing data and reports,
- Assemble supporting GIS data for the study area,
- Review agricultural sediment yield assessment methods,
- Estimate sediment yield from agricultural watersheds,
- Identify watersheds with significant sediment yield potential, and
- Evaluate agricultural sediment reduction measures.

The following report details the steps taken to quantify agricultural sediment contribution to the Lower Granite Reservoir backwater area near both Lewiston, ID and Clarkston, WA as well as tributary watersheds downstream on the lower Snake. It was not our intent to duplicate the TetraTech (2006) study or ongoing efforts by the USACE so duplication was avoided where possible. However, we did use significant amounts of this information and is so cited in this report.

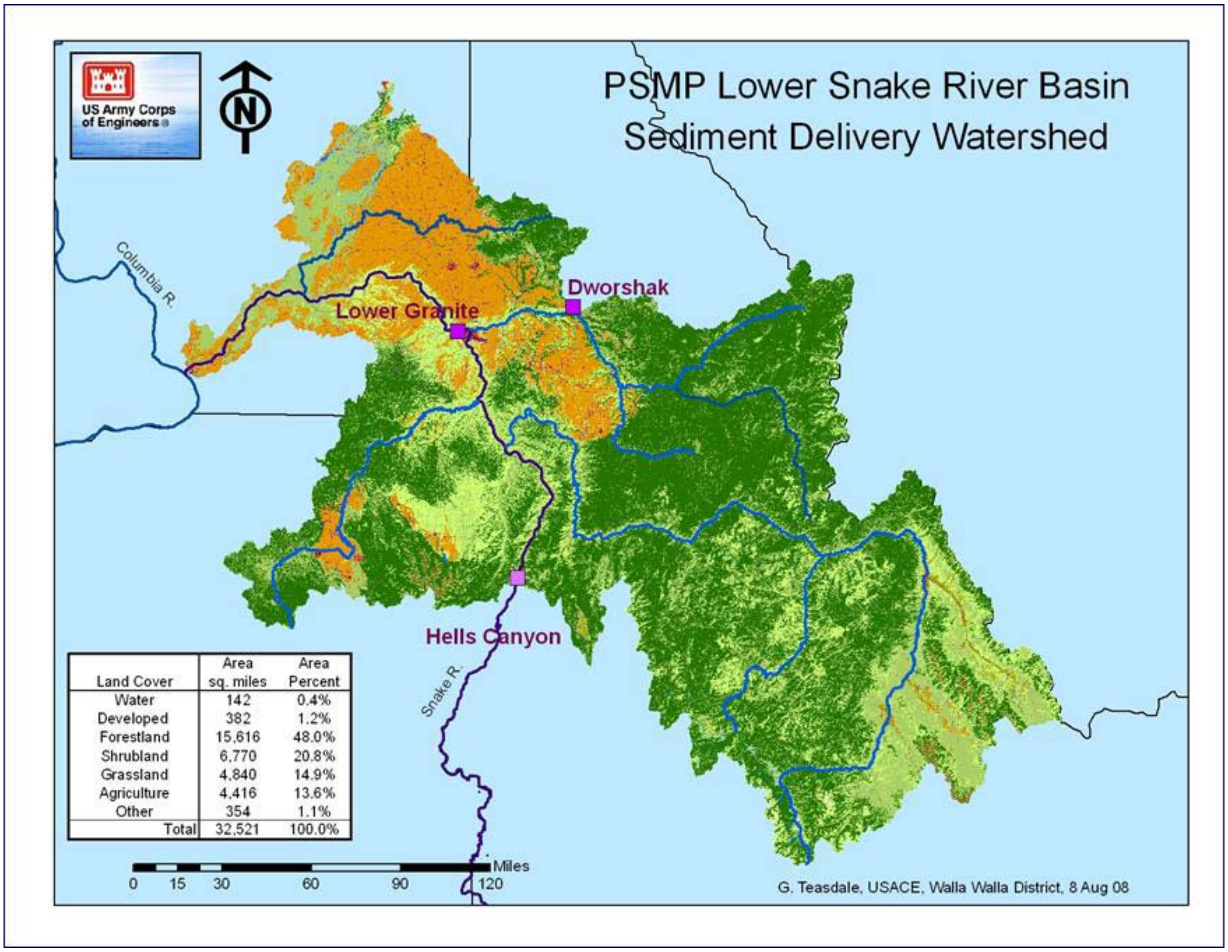

Figure 1. Contributing sediment basins in the lower Snake River watershed (USACE, 2008).

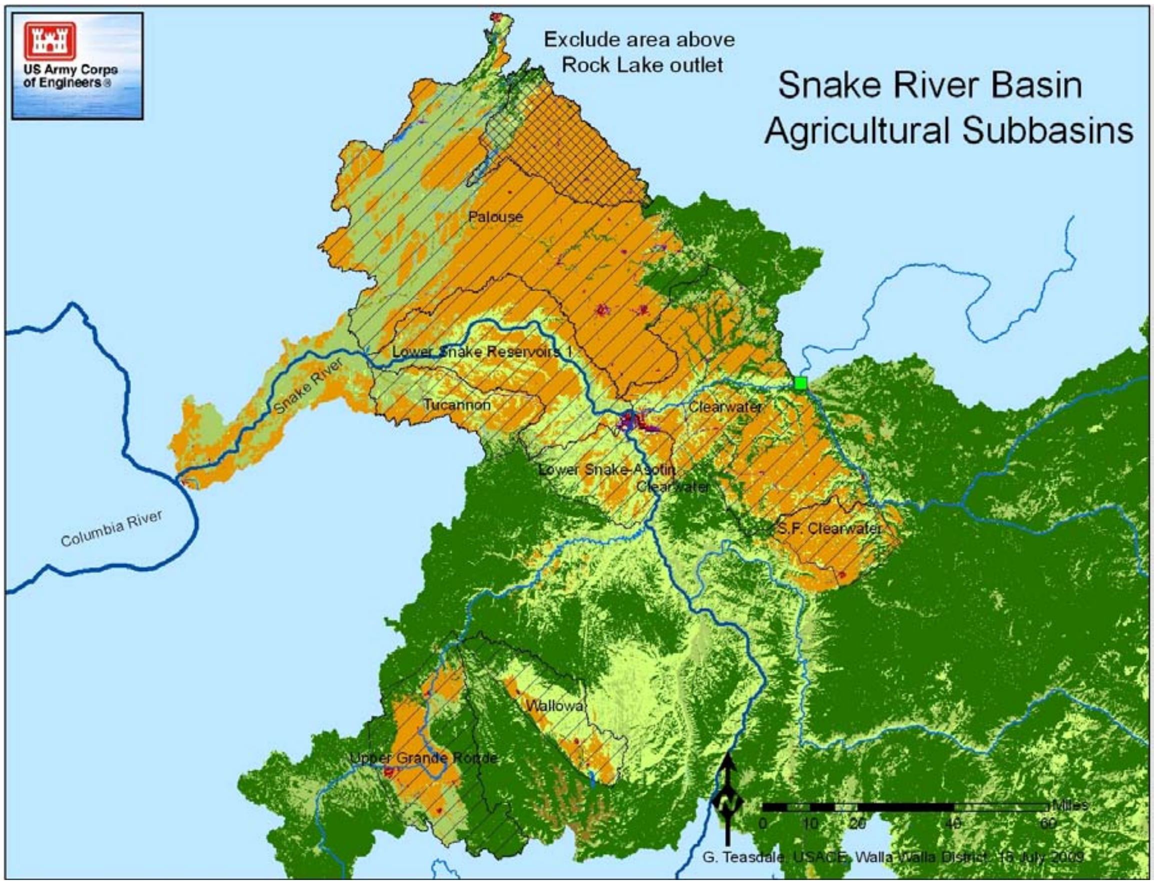

Figure 2. Study area of agricultural lands within lower Snake River watershed (USACE 2008).

2.0 Background

As an initial task, we reviewed a considerable amount of existing literature on sediment erosion, transport, and deposition with a bent towards agricultural production. Sediment generation, transport and deposition processes are discussed throughout the literature and periodically reviewed (Rose 1993; Haan et al. 1994; Prosser and Rustomji 2000). This document contains a brief summary of this literature. Because of an overwhelming amount of work in this area, we tended to focus on relevant data sets and studies conducted in the Pacific Northwest or with broad-based application nationally or globally.

Early studies of soil erosion and transport typically divided sediment sources broadly into sheet and channel supplies (Roehl 1962). Sheet erosion consisted of upland sources while channel erosion included gully, valley trenching, streambed, and stream bank erosion. Today, rather than lumping sources together, researchers recognize and have been working towards quantifying each distinct erosion component. Arguably, some theories and practices are still in their development phase and must be used with caution due to the uncertainty of results or the limited amount of validation. Furthermore, while there are many more unique sources of sediment in most watersheds, it is often difficult to distinguish between them with high degrees of precision due to the complex paths, interactions, and limited long-term data availability. Consequently, techniques that lump sediment into a single category still have potential uses.

In this report, upland erosion (sheet and rill) and channel erosion (gully and streambank) processes and models focusing on agricultural areas are examined.

1. Sheet and Rill Erosion

Computerized applications for watershed surface erosion processes can be broadly categorized into the following groups (USBR, 2006):

a. Empirical models
b. Physically-based models
c. Mixed empirical/physical models
d. GIS-based models

Empirical models of erosion rates are typically based on one of the following methods (Randle et al. 2006):

a1. Universal Soil Loss Equation (USLE) or one of its modified versions
a2. Sediment yield as a function of drainage area
a3. Sediment yield as a function of drainage characteristics

Although often criticized in the literature (often by those promoting a “better” approach), there are also staunch supporters of the USLE approach. Originally developed for small hillslope applications, the USLE and its variations have been incorporated into many catchment scale erosion and sediment transport modeling applications (Kinnell and Risse 1998; Merritt et al. 2003). However, the use of USLE outside the U.S. has been limited by the perceived lack of data for the parameters required to run the model under new conditions (Loch and Rosewell 1992).

Expressions predicting annual sediment yield as a function of drainage area (a2) are rather simple regression equations often shown as some form of Yang's (1973) unit stream power equation can be used as a rational tool for the prediction of sheet and rill erosion rate.

In 1968, the Pacific Southwest Inter-Agency Committee (PSIAC 1968) developed a sediment yield classification procedure comprised of surface geology, soils, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion that predicted sediment yield as a function of nine drainage basin characteristics (a3). Strand (1975) and Strand and Pemberton (1982) developed an empirical model based solely on contributing watershed area.

2. Channel Erosion

   a. Gully erosion
   b. Valley trenching
   c. Streambed erosion
   d. Streambank erosion

Most sheet and rill erosion models omit the impact of channel erosion except in aggregate of the calibration procedure. Investigations of both ephemeral and permanent gullies is not a new field of study but it is of growing importance as research suggests that ephemeral gullies act as the conduits for sediment delivery to streams and rivers (Teasdale and Barber 2008) and permanent gullies are related to land use/land cover changes (Nyssen et al. 2006; Tebebu et al. 2010). Permanent gullies can be defined as gullies too deep to pass over with ordinary farm tillage equipment; typically deeper than 0.5 m (Poesen et al. 2003). As shown in Figure 3, ephemeral gullies are shallower. Gully erosion typically occurs because of macrorelief features of a watershed and hydrologic events. Gully erosion models range from stochastic models to process-based representations of the system (Bull and Kirkby 1997). Haan et al. (1994) provided a discussion of ephemeral gullies and headwall gullies as well as computation methods aimed at including gully erosion in sediment predictions.

Figure 3. Regional example of ephemeral gully erosion and deposition zone.

In general, there are three types of streambeds to consider: 1) bed rock, 2) coarse-bed alluvial, and 3) fine-bed alluvial (Howard et al. 1994). The governing mechanics for erosion depend upon the type of bed being considered. Stream channel incision processes have typically been modeled by excess shear stress, total stream power, or stream power per unit bed area functions. Numerous mechanistic theories of long-term river profile development have been proposed in the literature (Howard and Kerby 1983; Beaumont et al. 1992; Slingerland et al. 1997; Whipple and Tucker 1999). While the underlying assumptions may be very different, most theories revolve around: 1) detachment-limited models (e.g. stream erosion law), 2) transport-limited models, or 3) hybrid models (Tucker and Whipple 2002).

Although no particular feature is necessarily conclusive evidence by itself, bed erosion may be indicated by (Queensland Government 2009):

- vertical headcuts,
- steep or mobile riffles,
- streambed weathering,

• extensive bank erosion on both sides of the stream or river,

• headcuts on tributaries (hanging valleys),

• changes in channel widths between disturbed and undisturbed reaches,

• exposure of ancient logs and rock bars in the stream bed,

• marks on bridge pylons of the old bed level, and

• wider, shallower reaches downstream of a headcut and fewer deep holes.

These processes may be analyzed individually or in a lumped parameter fashion. For example, Flores-Cervantes et al. (2006) developed a model to estimate horizontal headcut retreat as a function of discharge, height of the headcut, upstream slope, and relevant land surface and soil properties for soil erosion.

Streambank erosion consists of two processes: basal erosion due to fluvial hydraulic force and bank failure under the influence of gravity (Duan 2005). Streambank erosion rates are determined by a complex combination of factors (Wolman 1959; Knighton 1998). These factors can be categorized into several groups:

(1) cross-sectional and longitudinal characteristics;
(2) parameters of flow conditions;
(3) rainfall conditions;
(4) temperature conditions, primarily the influence of frost;
(5) vegetation and soil erodibility; and
(6) sediment characteristics.

Each group of influencing factors contains variables that may affect streambank erosion rates.

A significant amount research has been conducted in order to analyze and predict stream bank erosion (Hooke 1979; Lawler 1986; Rosgen 1996; Simon and Darby 2002). Hooke (1979) conducted a field study of river banks and concluded that two main methods of bank erosion are corrasion and slumping and that these appeared to be associated with the influence of river flow levels and antecedent precipitation conditions, respectively. Streambank erosion and channel form have been shown to be impacted by land use changes such as afforestation and urbanization (Murgatroyd and Ternan, 2006) as well as riparian condition. For streambanks containing large quantities of silts and clays (cohesive soils), Julian and Torres (2005) found that hydraulic erosion of cohesive riverbanks is dictated by flow peak intensities. Figure 4 shows a typical example of streambank erosion in the lower Snake River basin.

It is often difficult to separate streambed from stream bank erosion and the causes of one often lead to the other. For instance, Alonso and Combs (1990) and Langendoen and Simon (2008) found that bed lowering caused bank instability and widening of stream channels. As a result, the two are often combined in a single prediction model. Complicating watershed-scale analysis of sediment is a usual change in sediment sources going downstream. Brune (1951) was one of the first to find that bottomland sources such as streambank erosion and valley trenching became more important and upland sources such as sheet and gully erosion decreased in importance as watershed area increased.

Where tied directly to agricultural activities and management options, the importance of these concepts and other controlling factors will be examined more thoroughly in the discussion of models.

Figure 4. Streambank erosion on Charley Creek near Asotin, WA.

3.0 Approach Methodologies

3.1 Assemble Supporting GIS Data for the Study Area

The first National Land Cover Dataset (NLCD) created a 30-meter resolution land cover data layer of the conterminous United States from 1992 Landsat Thematic Mapper (TM) imagery and thus was referred to as NLCD 1992 (Vogelmann et al. 2001). In 2007, Howard et al. (2007) released an updated version of the NLCE 1992 data based on Landsat 5 and Landsat 7 imagery collected in 2001 called NLCD 2001. The new database contains 16 classes of land cover, the percent tree canopy (10% increments), and the percent urban imperviousness (10% increments) for every 30-meter cell in the conterminous 48 states. The 16 land cover classes are shown in Table 1.

Table 1. NLCD 2001 land cover class descriptions.

NLCD Land Cover Classes	
Open Water	Evergreen Forest
Perennial Ice/Snow	Mixed Forest
Developed, Open Space	Shrub/Scrub
Developed, Low Intensity	Grassland/Herbaceous
Developed, Medium Intensity	Hay/Pasture
Developed, High Intensity	Cultivated Crops
Barren Land	Woody Wetlands
Deciduous Forest	Emergent Herbaceous Wetlands

The US Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) has also used remote sensing to develop information specifically related to agricultural cropland. The NASS Cropland Data Layer (CDL) is a raster, geo-referenced, crop-specific land cover data layer with a ground resolution of 56 meters (0.77 acres) and is available through the geospatial data gateway (http://datagateway.nrcs.usda.gov/). A local example of the images is presented in Figure 5. According to the metadata, the NASS CDL is produced using satellite imagery from the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during the current growing season. In some states, cropland data layers used Landsat 5 TM and or Landsat 7 enhanced thematic mapper plus (ETM+) satellite imagery to supplement the classification. Ancillary classification inputs include: the US Geological Survey (USGS) National Elevation Dataset (NED), the USGS National Land Cover Dataset 2001 (NLCD 2001), and the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) 250 meter 16 day Normalized Difference Vegetation Index (NDVI) composites. Agricultural training and validation data are derived from the Farm Service Agency (FSA) Common Land Unit (CLU) Program. The NLCD 2001 is used as non-agricultural training and validation data. The strength and emphasis of the CDL is agricultural land cover in that it has far more crop types than the NLCD data set. Table 2 lists some of the more than 75 crop and land use types readily available for Washington.

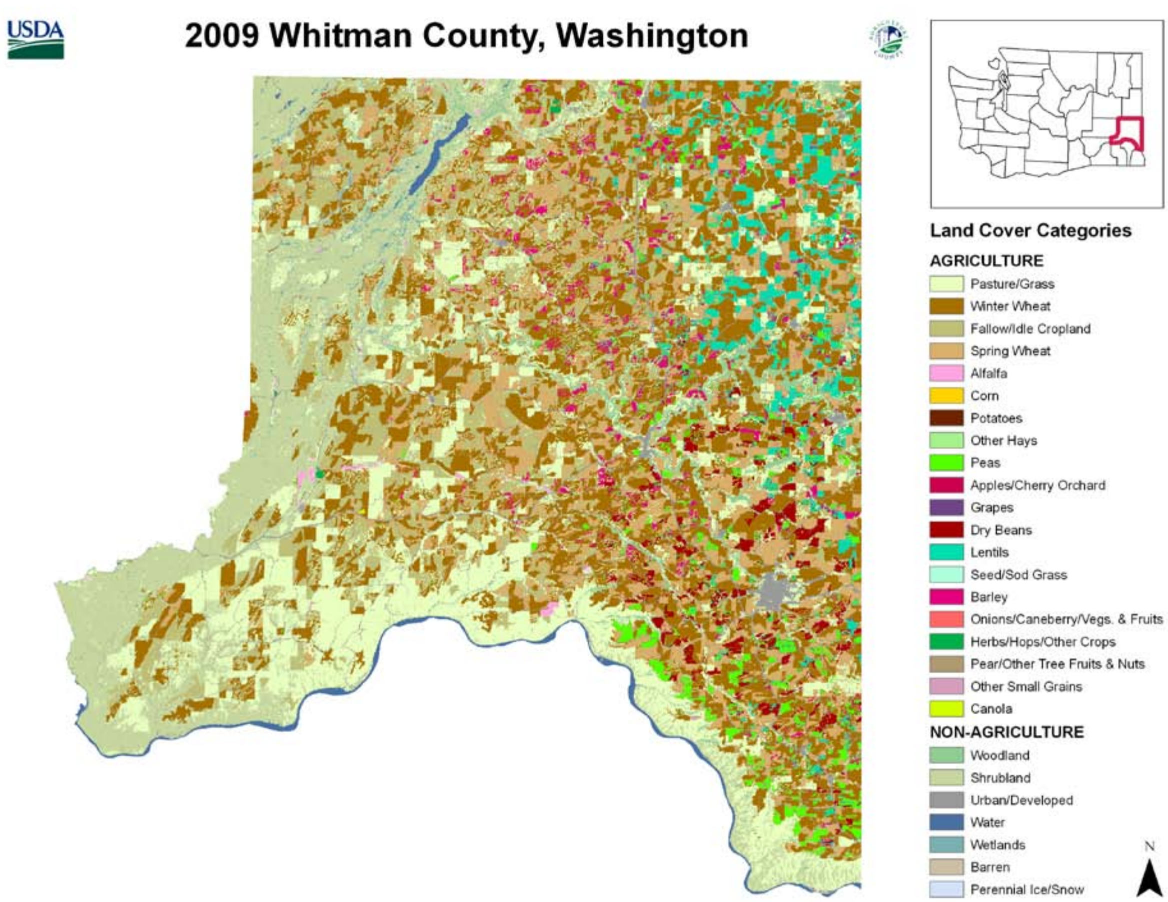

Figure 5. Example CDL data layer for Whitman County, Washington

Prior to 2006, the classification process used to create the CDL was based on a maximum likelihood classifier approach using an in-house software package. The CDL relied mainly on data from the Landsat TM/ETM satellite which had a 16-day revisit. And the in-house software limited the use of only two scenes per classification. Since 2006, Leica Geosystems ERDAS Imagine software has been used in the pre- and post- processing of all raster-based data. ESRI ArcGIS has been used to prepare the vector-based training and validation data. Rulequest See5.0 has been used to create a decision tree based classifier as opposed to the maximum likelihood classifier. The strength of the CDL is in its agricultural classifications. Due to the extensive agricultural training data provided by the Farm Service Agency, the major crop types for a CDL state will normally have a classification accuracy of 85% to 95%.

Table 2. NASS CDL 2007 major agricultural land cover class descriptions for Washington.

CDL Land Cover Classes	
Corn	Apple/Cherry Orchards
Pasture/Grass	Peaches
Winter Wheat	Grapes
Spring Wheat	Dry Beans
Alfalfa	Lentils
Cotton	Seed/Sod Grass
Potatoes	Barley
Other Hay	Onions/Caneberry/Vegetables/Fruits
Peas	Herbs
Fallow	Hops
Flaxseed	Pears/other
Other Small Grains	Canola
Rape Seed	Wetlands
Sugarbeets	Mustard

The National Agriculture Imagery Program (NAIP) acquires aerial imagery during the agricultural growing seasons in the continental U.S. NAIP imagery is acquired at a one-meter ground sample distance (GSD) with a horizontal accuracy that matches within six meters of photo-identifiable ground control points, which are used during image inspection. The FSA imagery acquisition cycle was 5-years beginning in 2003, 2008 was a transition year, and a 3-year cycle began in 2009. NAIP imagery products are available either as digital ortho quarter quad tiles (DOQQs) or as compressed county mosaics (CCM). DOQQs are available on-line at http://gis.apfo.usda.gov/arcgis/services. CCMs are available for free download through the USDA Geospatial Data Gateway, http://datagateway.nrcs.usda.gov/.

3.2 Summary and Review of Existing Data and Reports

Compilation of reports and data related to agricultural sediment yield

Reports and information related to agricultural sediment yield were compiled for the study region. A detailed list of available reports is provided in Appendix A of this report. As studies of erosion and sediment yield in mixed-land use watersheds typically address sources other than strictly agriculture, the evaluation will occasionally refer to these other sources.

Evaluation of reports and data

TetraTech (2006) provided an overview of sediment sources and yield for the Lower Snake River Basin with additional reference to management and restoration opportunities. Information compiled in TetraTech (2006) was partly derived from the comprehensive assessment of ecosystem components in the interior Columbia Basin by Quigley and Arbelbide (1997). In the Lower Snake River Basin, agriculture and urban land use are 23% of the total land area (see Table 3). The Lower Snake River Basin does not include areas that contribute sediment below Lower Granite Dam such as the Palouse River Basin.

The Salmon River subbasin is not part of the analysis of this project. This subbasin, however, should be considered as potential sources of coarse grained sediments due to hydrologic and riparian disturbances. TetraTech (2006) identifies the Lemhi watershed as having a rating of high hydrologic disturbance, high surface soil erosion hazard in Pahsimeroi, Lemhi, and Lower Salmon watersheds, high sediment delivery hazard in the Lower Salmon and Little Salmon watersheds. Furthermore, highly erodible cropland occurs in the northern edge of the Lower Salmon watershed. Out of 89 water bodies in this subbasin listed in Section 303(d) in 1998, 88 were listed for sediment concerns.

Table 3. Land Cover of Agriculture/Urban above Lower Granite Dam

(derived from Table 2 in TetraTech 2006).

Geographic area	Agriculture/Urban percentage
Salmon subbasin	3
Clearwater subbasin (not incl. North Fork Clearwater)	24
Lower Snake River basin – Hells Canyon Dam to Clearwater	22
Grande Ronde subbasin	17
Lower Snake River basin – Clearwater to Columbia	79
Total Lower Snake River Basin area	23

The Natural Resources Conservation Service (NRCS) has produced sediment loss estimates at the country level to identify the highest potential for sediment and nutrient loss from farm fields, wind erosion, and soil quality degradation, areas of the country that would likely benefit the most from conservation practices (Potter et al. 2006; NRCS 1997). They used the National Nutrient Loss and Soil Carbon (NNLSC) database from 1997 National Resource Inventory (NRI) points to represent cropland land use patterns and resource conditions. Erosion by water includes sheet and rill erosion and excludes gully erosion. Within an 8-digit hydrologic unit, dot counts represent acreage totals correctly plus or minus one dot to account for remainders. Map 5083 does not show rates of erosion or how much erosion has occurred, and each dot on the map represents 5000 acres. Data also were not collected on Federal land, and data are not available for Alaska or the Pacific Basin.

Potter et al. (2006) estimated sediment loss using MUSLE. The West was sparsely covered, and non-irrigated crops only included barley, spring wheat and winter wheat. The range of soil loss in tons/ac was 0.5 to 1.3 for these crops. Tillage practices in the West reduced sediment loss from 2.1 using conventional tillage to 1.3 and 0.8 for all crops (irrigated and non-irrigated) using mulch tillage and no-till, respectively. Conservation practices evaluated for the Western part of the USA included terraces, which are not typically used in the study area. None of the subbasins in the study area were identified as critical areas in the NRI CEAP study. This can be due to sparse coverage of the area, or the type of data input in the EPIC model for the purposes of the model simulations.

Clearwater River Subbasin:

Land ownership in this subbasin is 62% federal, 1% Nez Perce Tribe, 3% State of Idaho, and 33% private. Agricultural land use occurs in the Middle Fork Clearwater (18%), South Fork Clearwater (23%), and Clearwater (57%). Agriculture consists of wheat-barley and rangeland. Surface erosion hazard is high in Middle Fork Clearwater and Clearwater watersheds, and moderate to high in the South Fork Clearwater watershed. Sediment delivery hazard is mod-high or high in all watersheds within this subbasin (see Table 19 in TetraTech 2006). The South Fork and Clearwater River watersheds have Highly Erodible Lands according to NRCS (1997). Surface erosion was estimated by Boll et al. (2001) for agricultural areas within the basin. Teasdale and Barber (2005) estimated ephemeral gully erosion in the Potlatch River watershed at less than 0.5 tons/acre. In 1998, 540 stream segments were 303(d) listed (70% in Lower Clearwater, 19% in Middle Fork Clearwater, and 9% in South Fork Clearwater). The TetraTech report lists several that have been delisted since that time.

Overall TetraTech (2006) concluded that agricultural and forest management in the Clearwater, South Fork Clearwater and Middle Fork Clearwater watersheds are most promising for sediment reductions. BMPs have been published in the Idaho Agricultural Pollution Abatement Plan (Resource Planning Ltd. 2003) for agriculture (including grazing), but they are largely voluntary at this time. Restoration of riparian areas, and limiting field erosion and delivery to streams are important.

The Potlatch River basin is part of the Clearwater River subbasin. Total area of the Potlatch Basin is 1540 km^2 (590 mi^2). The upper watershed is predominately forestland of mixed ownership. The southern part of the watershed is the easternmost extension of the Palouse prairie and is dissected by deep canyonlands of the lower tributary drainages. Land use is predominantly dryland agriculture intermixed with areas of rural residential development. Dechert (2004) used RUSLE2 model to predict surface erosion from the agricultural segments of the watershed. The study area covered 736 km^2 (284 mi^2) of land situated in the lower Potlatch River basin. Six subbasins (Big Bear, Cedar, Little Bear, Little Potlatch, Middle Potlatch, and Pine Creek) are located in the lower watershed as part of the Northwestern Wheat and Range Region. Table 4 illustrates the erosion values used by Teasdale and Barber (2008) in their analysis of ephemeral gullies in the system.

There are other sources of sediment in the basin other than cropland agriculture. Figure 6 shows an example of a clear-cut section of forest near Helmer, Idaho. Logging activities such as this have been shown to contribute significant amounts of sediment.

Table 4. RUSLE2 surface erosion rates for the Potlatch agricultural watersheds. (Adapted from Dechert, 2004)

Subbasin	Mean Surface Erosion (mton/km^2)	Standard Deviation (mton/ km^2)	Mean Surface Erosion (ton/acre)	Standard Deviation (ton/acre)
Big Bear	802.8	2,060.0	3.57	9.16
Cedar	524.0	1,805.8	2.33	8.03
Little Bear	645.4	1,675.4	2.87	7.45
Little Potlatch	1,540.5	1,603.4	6.85	7.13
Middle Potlatch	1,164.9	1,742.9	5.18	7.75
Pine	951.3	2,473.8	4.23	11.00

Figure 6. Clear-cut logging near Helmer, ID in the Potlatch basin.

Snake River Basin (below Hells Canyon Dam):

This subbasin consists of Hells Canyon, Imnaha, and Lower Snake Asotin. The Asotin watershed contains 47% agricultural/urban land, including grassland and cropland at lower elevations. Hydrologic disturbance is high in the Lower Snake – Asotin watershed. For the Asotin, a review of the Asotin County Conservation District Subbasin Plan shows the changes in stream channel and riparian areas, gully erosion, and other man-made changes. The subbasin plan addresses these issues. Surface soil erosion and sediment delivery hazards are high in the entire subbasin.

The NRCS analysis of cropland found that the geographic area had no areas of highly erodible cropland and no areas of highly erodible or non-highly erodible cropland with excessive erosion above the tolerable soil erosion rate, except for some areas in the lower elevations of the Lower Snake-Asotin watershed (NRCS 2000). Tammany Creek is mentioned as having sheet and rill erosion, in addition to grazing lands, and other sources. Excessive erosion was estimated at 3,000 tons per year during Dec-Jun. Imnaha and Asotin creek are also reviewed, but there is no clear indication how much sheet and rill erosion play a role in the overall erosion and sediment delivery. Agricultural BMPs include no-till/direct seeding, but no percentages of implementation are provided. Figure 7 illustrates a typical direct seeding operation within the Asotin Creek watershed. Research has demonstrated that this type of BMP is highly effective in reducing sediment loading. Imnaha is considered in good condition. Asotin's plan is considered as an improvement that will reduce sediment considerably.

Figure 7. Direct seed winter wheat in stubble in Asotin County.

Grande Ronde River Subbasin:

This Oregon subbasin has on average 17% agriculture/urban, with 22% in Upper Grande Ronde, 17% in Wallowa, and 11% in Lower Grande Ronde. Private ownership occurs at lower elevations, comprising about half of the subbasin. Cropland erosion may be present, but it is not the major source for sediment originating in the subbasin. Hydrologic disturbance is high in Upper Grande Ronde. Surface erosion hazard and sediment delivery hazard are high in all watersheds in this subbasin. Upper Grande Ronde and Wallowa watersheds have some highly erodible cropland. Several stream segments (20 in the Grande Ronde subbasin, two in the Lower Grande Ronde, and four in the Wallowa) were on 303(d) list in 1998. Practices that improve vegetative conditions are high priorities for improving water quality in the subbasin. Agricultural improvements have been achieved through CRP, CREP and WRP. In addition to reducing streambank erosion, creation of wetlands and filter strips for drainage from agricultural areas is important.

Lower Snake River Basin (Mouth to Lower Granite Reservoir):

Watersheds in this region include Palouse, Rock, Tucannon, and Lower Snake basins. These basins are mostly downstream of Lower Granite Reservoir. Dryland agriculture dominates this subbasin with 79% on average. Private ownership is at 92%. Sediment source in this area is wind-blown loess, producing fine sediment (silts and clays). A combination of conventional, conservation and no-tillage is used, with the majority in conservation or no-till. In addition to sheet and rill erosion, gully erosion is a major source of sediment. CRP is found on highly erodible land. Surface soil erosion hazard is high in all watersheds in this subbasin. Sediment delivery hazard is high in Tucannon. Conservation efforts, in particular as part of STEEP, have reduced erosion and sediment delivery in the Palouse region (see Brooks et al. 2010). NRCS (2000) indicates extensive areas with excessive erosion on highly erodible lands. TetraTech (2006) reviewed studies done in the watersheds of this subbasin.

A major recommendation from TetraTech (2006) is to do a screening effort to identify the watersheds and subwatersheds with the highest sediment production. A distinction should be made if the source is natural or man-made, and focus on the man-made watersheds to suggest further reductions. This study has followed this recommendation.

In a Tri-state effort in WA, OR, and ID, Kok et al. (2009) investigated the long-term impacts of conservation farming in the Pacific Northwest Wheatland. They found that soil erosion was reduced from 20 tons/ac/yr to 5 tons/ac/yr since 1975. Specific changes in farming practices related to erosion are summarized here. The moldboard plow (see Figure 8) has been replaced by less aggressive equipment such as chisel plows, sweeps, and field cultivators that conserve surface residues (see Figure 9). Most tillage following legume crops has been eliminated and reduced by 80% to 90% after spring cereals and 40% after winter wheat. Fallow land was reduced from 13% in high precipitation zone to zero. Fallow reduced somewhat in the intermediate precipitation zone, but shifted from tillage fallow to chemical fallow (see Figure 10). In the low precipitation zone, fallowing is still present on about the same acreage as 30 years ago, but conservation tillage fallow and chemical fallow have increased dramatically. Conservation tillage has become standard practice on most farms. Crop rotations have increased from 2-yr wheat-pea to 3-yr winter wheat-spring cereal - grain legume. The trend of increased use of no-till was initiated and is likely to continue. Increased yields have increased the amount of residue, which affects the soil erosion process, but in the high precipitation zone the high residue prevents adoption of no-till. Figure 1a shows soil erosion reductions in for 1975, 1990, and 2005 for the high, intermediate, and low precipitation zone, for different farming systems.

Figure 8. Aftermath of moldboard plow tillage.

McCool and Roe (2005) did analysis of soil erosion reduction in the Palouse River basin, focusing on winter erosion and conservation practices. While the hazards related to winter hydrology (predominantly frozen soil) were reduced from 1979 to 1994, the increase in conservation practices contributed to reduced soil erosion.

Figure 9. Example of high residue cropland.

Figure 10. Chemical fallow (upper) versus traditional fallow (lower).

Brooks et al. 2010 reported on long-term sediment loading trends in the Paradise Creek watershed. They found a statistically significant decreasing trend in overall sediment load based on detailed event-based sampling from 2001-2009 and three day-per week grab samples collected over the last 28 years. This decreasing sediment load can be attributed to conversion from conventional tillage systems to minimum tillage and perennial grasses through the Conservation Reserve Program, practices initiated in the late 1970s and early 1980s. Over the last 10 years (1999 to 2009) management practices have targeted gully erosion and stream bank failures. Preliminary modeling results and empirical evidence indicate that delayed reduction in sediment load at the watershed outlet may be caused by sediment storage in the stream channel.

The importance of infrequent large storms in producing large sediment loads is demonstrated at the USGS Suspended Sediment Database of major rivers in the United States (http://co.water.usgs.gov/sediment/selHistogram.cfm) which includes a histogram of the proportion of suspended sediment discharged during 1, 10, and 100 percent of the year at Hooper WA (see Figure 11). As illustrated in the figure, the majority of sediment loading at this location occurs in short, high flow periods. This has severe implications on design of sediment BMPs with large structures needed for meaningful reduction. Note that sediment collection at the Hooper station was only active from 1962 to 1971.

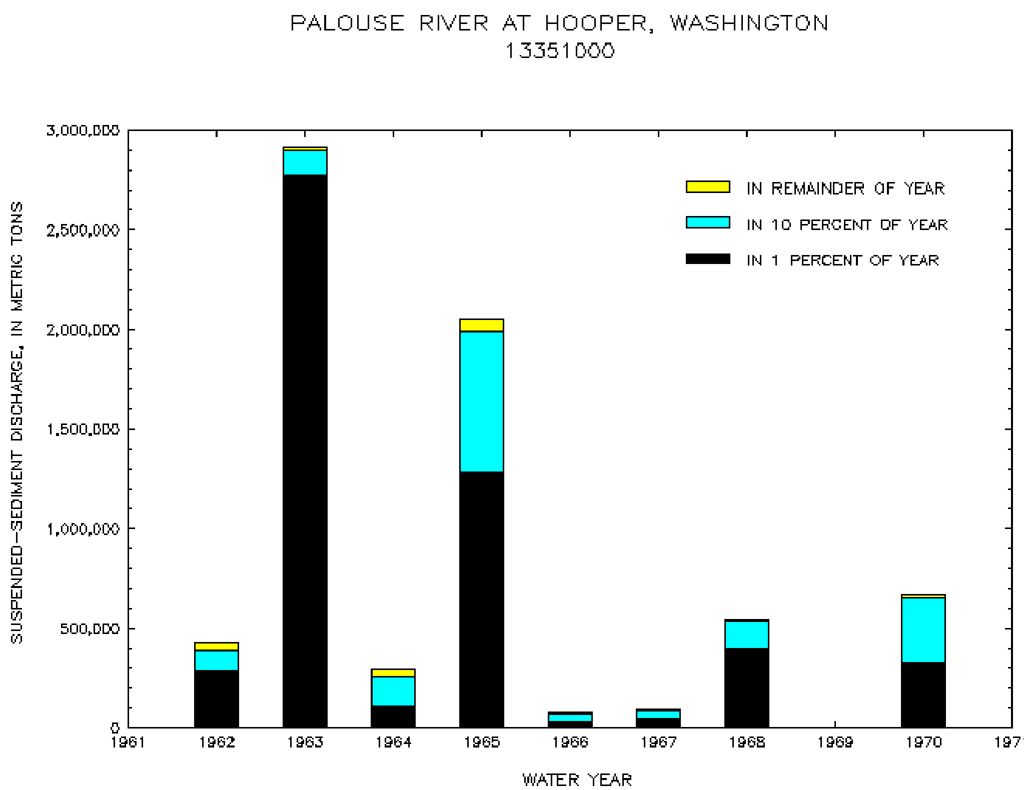

Figure 11. Suspended sediment is transported from the Palouse River Basin.

This phenomenon can be seen at other locations throughout the study area. An extreme case in point occurred during the 1997 flood where sediments were scoured from long reaches of tributary streams leaving gravel bars and relatively poor riparian conditions in several areas. Figure 12 illustrates this on George Creek near Asotin, Washington. This can be a source of sediment downstream for years.

Figure 12. Scour of sediments on George Creek as a result of 1997 flood.

See Appendix A for a database of related to studies (spreadsheet: AppendixA-Database-reports.xls). We are compiling information in watershed specific reports guided by the following questions:

<u>Data related to sediment yield from agricultural watersheds</u>

i. Compilation of reports and data related to agricultural sediment yield
ii. Written evaluation of the reports and data
iii. Database listing of reports and data
iv. Transfer of reports datasets to Corps

3.3 Review of Agricultural Sediment Yield Assessment Methods

There are numerous methods for determining soil erosion/sediment yield estimates. Soil erosion models range from detailed plot scale models to coarse watershed scale estimates. The two primary objectives that drive model selection in this study are the desire to: (1) quantify the sediment yield from a large region and (2) evaluate the potential for reducing sediment load for specific areas through implementation of best management practices.

Fundamentally and as previously stated, soil erosion models can be classified into three primary categories:

- empirical,
- semi-empirical/conceptual, and
- physically-based models.

Empirical models are often developed in regions having a large observation data set and are often simple models based on a few easily measured parameters. The USLE and subsequent revised-USLE (RUSLE) model are examples of an empirical modeling approach. RUSLE was developed from large, long term experimental datasets collected over many years at various locations around the US. RUSLE provides long term average hillslope scale soil erosion rates using climate, soils, slope length, slope steepness, crop rotation, and tillage parameters. It is a well accepted approach which can be applied to large areas through raster-based GIS calculations. This approach has been used in several TMDL watershed studies in the Snake River Basin. However empirical approaches are limited to regions which have long-term experimental data and assessment of management practices are often limited by data availability.

Semi-empirical models attempt to make empirical models more transferable to other regions which lack experimental data sets by including some physically-based processes. The SWAT model and the RUSLE-2 models are examples of semi-empirical models. Erosion prediction in the SWAT model is based on the Modified USLE (MUSLE) approach where the climate factor (R), calculated in RUSLE based on mean annual rainfall characteristics, is based on daily runoff from rainfall. The MUSLE approach allows SWAT to predict daily erosion rates rather than 30 year average erosion rates through RUSLE. Although this adaptation allows the SWAT model to predict erosion for individual storms, the accuracy of the model is directly related to its ability to predict surface runoff. However, daily runoff in the SWAT model is simulated using curve-number (CN) approach which is also a semi-empirical approach. The CN approach was developed using large watershed datasets which related precipitation to runoff using various soil and vegetative factors. As with the empirical RUSLE approach the accuracy of the CN approach relies heavily on large experimental watershed data sets. In the absence of these datasets the accepted approach in the SWAT model is to calibrate the curve number until observed and predicted streamflow best match.

Physically-based models are based on fundamental hydrologic processes and erosion prediction is based on soil detachment, transport, and delivery mechanisms. Physically-based models rely only on measurable soil, vegetative, climate, and topographic parameters. Although these models are adaptable to any region, the data requirements are often excessive and, because of their complexity, are often difficult to use. The Water Erosion Prediction Project (WEPP) model is an example of physically-based soil erosion models. The model uses physics-based equations to describe hydrologic and sediment generation and transport processes at hillslope scales. WEPP processes can be categorized as erosional processes, hydrological processes, plant growth and residue processes, water use processes, hydraulic processes and soil processes (Laflen et al. 1991). A detailed description of the WEPP model is provided below.

WEPP simulates soil detachment, deposition, transport and delivery through hillslope, channel, and structural impoundment units within a watershed (Flanagan and Nearing 1995). The model is based fundamentally on infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. Processes in WEPP include rill and interrill erosion, sediment transport, and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration, surface sealing, rill hydraulics, surface runoff, plant growth, residue decomposition, percolation, evaporation, transpiration, snow melt, frozen soil effects on infiltration and erodibility, climate, and effect of soil random roughness. Each hillslope can be divided into multiple overland flow elements to simulate flow from one land type to another (e.g., drainage from a disturbed upland area through a grass buffer).

Since its inception, the WEPP model was to become a wide-spread, physically-based management tool for the evaluation of management techniques. Much time and money was spent conducting experiments on a wide range of soil types across the country to develop parameter sets for soil, residue, and vegetative properties. Management files describing key temporal modifications to the plant, residue, and soil system (e.g., tillage, harvest) were developed for a wide variety of agriculturally- and forestry-based systems. The model accepts long term daily climate data or single storm event data. An auxiliary climate generator program, CLIGEN (Nicks and Lane 1989), creates long term climate files if meteorological data are not available.

There are numerous other physically-based models that have been proposed in the literature. Wicks and Bathurst (1996) developed a physically-based, spatially distributed erosion and sediment yield model called SHESED. The model is capable of simulating surface erosion as well as channel processes.

Parsons et al. (2001) examined agricultural non-point source water quality models including AGNPS, ANNIE/WDM, BLTM, CREAMS, EPIC, and others. Based on a number of previous limited evaluation studies conducted by others, they also compiled tables of model characteristics such as event or continuous simulation, spatial scale, computational time step, target audience, physiographic validation, user interface, hydrologic features, chemical transport, snowmelt, erosion, economics, and documentation.

Wheater et al. (1993) developed a classification system describing the process representation of the model as empirical, conceptual or physical-based. Merritt et al. (2003) used that system to review a range of models shown in Table 5 that explicitly consider sediment and sediment-associated pollutants. In addition to reviewing input requirements, output, and limitations, this review included a summary indicating which models included land surface sediment generation, transport, and deposition as well as rainfall-runoff processes and stream sediment generation, transport, and deposition.

Table 5. Summary of erosion and sediment transport models.

Model	Type	Scale	Reference
Water Quality:			
AGNPS	Conceptual	Small catchments	Young et al. 1987
ANSWERS	Physical	Small catchments	Beasley et al. 1980
CREAMS	Physical	Field (40-300 ha)	Knisel 1980
EMSS	Conceptual	Catchment	Vertessey et al. 2001
HSPF	Conceptual	Catchment	Johanson et al. 1980
IHACRES-WQ	Empirical-Conceptual	Catchment	Jakeman et al. 1990
IQQM	Conceptual	Catchment	DLWC 1995
LASCAM	Conceptual	Catchment	Viney and Sivalapan 1999
SWRRB	Conceptual	Catchment	
Erosion:			
GUEST	Physical	Plot	Yu et al. 1997
LISEM	Physical	Small catchment	Rose et al. 1997
PERFECT	Physical	Field	Littleboy et al. 1992b
SEDNET	Empirical/conceptual	Catchment	Prosser et al. 2001c
TOPOG	Physical	Hillslope	
USLE	Empirical	Hillslope	Wischmeier and Smith 1978
WEPP	Physical	Hillslope/catchment	Laflen et al. 1991
Stream Transport:			
MIKE-11	Physical	Catchment	Hanley et al. 1998

The Merritt et al. (2003) review clearly stated that computer technology has led to an explosion of models and that covering every model was not feasible. Kalin and Hantush (2003) conducted a cursory review of numerous sediment models for TMDL BMPs including SWAT and ANNAGNPS before focusing comparison efforts on a kinematic erosion (KINEROS-2) model (Smith et al. 1995) and a WMS-adapted gridded surface subsurface hydrologic analysis (GSSHA) model (Downer and Ogden 2002).

Aksoy and Kavvas (2005) conducted a review of hillslope and watershed scale erosion and sediment transport models. While some models overlapped those in the Merritt et al. (2003) study, their review also included the empirical model SEDD and physically-based models EUROSEM, KINEROS, WESP, CASC2D-SED, SEM, and SHESED (Wicks and Bathurst 1996). Even this is not an exhaustive list of models. Models such as LISEM (Hessel et al. 2003) report promise with respect to erosion and transport prediction but lack sufficient use to gauge the applicability of the model to watershed scale approaches.

Streambank and Streambed Erosion Models:

The location, timing, and magnitude of streambank erosion are difficult to predict. USDA researchers at the National Sedimentation Laboratory developed a channel evolution model referred to as CONCEPTS (conservational channel evolution and pollutant transport system) (Langendoen and Simon 2008) in response. The resistance of fine-grained materials to hydraulic and geotechnical erosion, the impact of pore-water pressures on failure dimensions and shearing resistance, and the role of riparian vegetation on matric suction, streambank permeability, and shearing resistance are used in CONCEPTS. The model was calibrated and tested using five years of data from Mississippi where the top-bank widened by over 11 feet. This may be typical of streams in the south and Midwest where streambanks have reportedly contributed as much as 80% of the total suspended load, but few examples of this rapid bank retreat exist here in the Pacific Northwest. Consequently, the data sets necessary to locally calibrate the CONCEPTS model do not exist and using the model without calibration would likely lead to significant errors in prediction due to parameter uncertainty.

Consider only the uncertainty in the resistance of fine-grained materials to hydraulic and geotechnical erosion component (commonly referred to as bed shear stress). There are many ways to estimate the critical shear stress found in the literature. Clark and Wynn (2007) compared field measurements of critical shear stress to Shield’s Diagram and several empirical methods and found results were different by as much as four orders of magnitude. Similarly, we examined a number of critical bed shear stress relationships. Theories developed for bed shear velocity and bed shear stress estimation are based on specific assumptions such as flow condition (e.g. laminar/turbulent flow, depth of water etc.), particle size of bed load, velocity distribution, and channel roughness (Kim et al. 2000). These theories can be grouped into three categories: (1) first-order moment statistics methods (mean)including the log profile (LP) method, average shear velocity method and quadratic stress law method; (2) second-order moment statistics (variance) including the Turbulent Kinetic Energy (TKE) method or Covariance (COV) method (also known as Reynolds stress method); and (3) spectral analysis methods such as the Inertial Dissipation (ID) method (Kim et al. 2000; Pope et al. 2006; Westenbroek, 2006).

The effect of methodology on critical shear stress using five different sizes of sand particles was examined by Rashid (2010). The particle size characteristics of these five different types of sediment are described in Table 6. These sand sizes are typical of the sand fractions found in the lower Snake River study area. Shear stresses were estimated using Shields' (1936), Log-profile (LP), Prandtl's, Turbulent Kinetic Energy (TKE), Reynolds stress (RS) method, and an equation proposed by Kim et al. (2000). Results of these analyses are shown in Table 7. As indicated, results can vary by an order of magnitude depending on approach. Local calibration of models is therefore essential.

Table 6. Physical properties of test sands.

Name of the sand type	Passed through (Sieve # - Opening in mm)	Retained at (Sieve # - Opening in mm)	Nominal size (mm)
A	20 - 0.850	25 - 0.710	0.780
B	25 - 0.710	40 - 0.425	0.567
C	40 - 0.425	50 - 0.300	0.360
D	60 – 0.250	80 – 0.180	0.215
E	100 – 0.150	200 – 0.075	0.113

Table 7. Critical bed shear stress for different sizes of sand particles.

Sand Type	Particle Size mm	Shields' N/m^2	LP N/m^2	Prandtl N/m^2	TKE N/m^2	Reynolds N/m^2	Kim et al. N/m^2
A	0.780	0.0425	0.1147	0.2786	0.1064	0.1355	0.0455
B	0.567	0.0300	0.0927	0.2252	0.0683	0.1035	0.0419
C	0.360	0.0208	0.0655	0.1992	0.0465	0.0758	0.0346
D	0.215	0.0180	0.0358	0.1623	0.0257	0.0308	0.0112
E	0.128	0.0149	0.0591	0.1715	0.0397	0.0686	0.0298

As in all sediment prediction phases, there is considerable uncertainty in streambed erosion calculations. Relatively small-scale phenomenon can have large impacts. For example, Smith et al. (2006) found a four-fold increase in bedload transport at bankfull discharge when large woody debris was removed previously stored upslope of debris buttresses or in low-energy hydraulic environments. Beck (1987) identified sources of inaccuracy due to: errors of aggregation, numerical errors of solution, errors of model structure, uncertainty due to unobserved system input disturbances (natural variability), and measurement errors associated with observed input and output field data.

Sediment Fate and Transport Models (Stream Transport):

Sediment transport models are available from a number of sources depending on the data set being used to calibrate and validate the model output. The two leading classes of river erosion models are detachment-limited and transport-limited (Tucker and Whipple, 2002). Models range from 1-dimensional analyses such as HEC-HMS (USACE model), 2-dimensional models such as SED2D, and 3-dimension models such as EFDC. The driving mechanisms within each type of model can be very different and most require significant calibration over a range of flow rates in order to produce reasonable results.

Three sediment transport modeling packages called CCHE1D, CCHE2D, and CCHE3D are in various stages of development by the National Center for Computational Hydroscience and Engineering at the University of Mississippi. CCHE1D uses a one-dimensional, non-equilibrium approach for the total-load transport. Flow and sediment calculations are initially decoupled but a coupled procedure is adopted in the sediment module to simultaneously solve the nonuniform sediment transport, bed change and bed material sorting equations. The sediment transport capacity is determined by four formulas: 1) Wu et al.'s (2000) formula, 2) the SEDTRA module (Garbrecht et al. 1995), 3) the modified Ackers and White equation (Proffit and Sutherland 1983), and 4) the modified Engelund and Hansen's formula (Wu and Vieira 2002).

CCHE2D model is a depth-averaged two-dimensional (2D) model for flow and sediment transport in rivers. It has two versions, one based on the Efficient Element Method (EEM) and the second based on the Finite Volume Method (FVM). The EEM-based version adopts the fully decoupled procedure for flow and sediment transport, while the FVM-based version adopts the semi-coupled procedure similar to that used in CCHE1D model. The FVM-based CCHE2D model is capable of simulating the mophodynamic processes in vegetated open channels, and the salinity and cohesive sediment transport in river estuaries. In both versions, the nonuniform total-load transport is simulated using the non-equilibrium approach. Sediment transport capacity can be determined by van Rijn's (1984) formula, Wu et al.'s (2000) formula, the SEDTRA module (Garbrecht et al. 1995), the modified Ackers and White's formula (Proffit and Sutherland 1983), or the modified Engelund and Hansen’s formula (Wu and Vieira 2002). The effect of secondary flow on the main flow and sediment transport in curved channels has also been considered in both versions. An enhanced version of the CCHE2D model was created to study alluvial channel migration by Duan et al. (2001).

CCHE3D simulates open-channel flows using the hydrostatic pressure assumption or solving the full Navier-Stokes equations. The CCHE3D sediment transport model is capable of computing general channel aggradation and degradation, local scour around hydraulic structures, sediment transport near water intake facilities, and other complex phenomenon.

3.4 Estimation of Sediment Yields from Agricultural Watersheds

Soil erosion was estimated for all agricultural watersheds using the GIS-based RUSLE modeling approach. This is the currently accepted approach for estimating long term soil erosion from agricultural areas by the USDA-Natural Resource Conservation Service. One of the most widely used watershed models, Soil Water Assessment Tool (SWAT), is based fundamentally on the RUSLE approach. The most recent version of the RUSLE approach is RUSLE2. RUSLE2 has improved physically-based algorithms for tracking soil residue and organic matter changes for a wide range of tillage practices. Rather than relying on empirical C factors, developers created a user-friendly interface to more directly capture changes in the residue cover for specific tillage operations. Crop residue build-up and decay is directly related to tillage and crop yields. Although RUSLE2 provides a more detailed assessment of effects of conservations practices on soil erosion from specific hillslopes, it has not been developed to be applied to large watersheds. The SWAT model can be applied to large regions, however soil erosion prediction has been linked to event based runoff predictions following the MUSLE adaptation of the USLE approach. Unfortunately the runoff prediction in the SWAT model is based on the SCS-Curve Number approach which has not been fully adopted or developed for the low-intensity rainfall event characteristics of the Pacific Northwest. In this analysis we have chosen to use a GIS-based RUSLE analysis which has been used successfully to estimate soil erosion for several watersheds in the Clearwater basin (see Boll et al. 2001 and IDEQ 2003) as a large-scale, Tier II screening approach and we have used the RUSLE2 and WEPP models as more detailed hillslope-scale Tier I assessments at specific locations in the basins later in this report.

Tier I Hillslope-scale Assessment

One of the greatest challenges in conducting watershed-scale soil erosion models is identifying the type of tillage practices being used in each watershed. Fortunately a recent study was conducted by Kok et al. (2009) where farmer interviews and interviews with scientists from the NRCS were used to identify current tillage practices and identify how farming practices have changed over the last thirty years. Drive-by windshield surveys were also conducted throughout the Palouse region to quantify the percent of farmers who have adopted no-tillage, reduced tillage, and conventional tillage practices. With this information Kok et al. (2009) was able to use the RUSLE2 model to conduct a Tier I assessment of the impact of current conservation practices on soil erosion throughout the region. Soil erosion rates were simulated using RUSLE2 for typical farming practices from 1975, 1990, and 2005 in the high, intermediate, and low precipitation zones of the dryland wheat farming regions of Washington, Oregon, and Idaho. One of the most important contributions of the Kok et al. (2009) study was developing a record of specific tillage practices for each of the precipitation zones and estimating the percentage of farmers in the region which followed a specific tillage practice. Simulated erosion rates for specific suites of tillage practices were weighted using estimates of the percent of the area that the particular practice had been applied to provide an average erosion rate for each precipitation zone.

The RUSLE2 analysis performed by Kok et al. (2009) showed significant reductions in overall sediment load within each precipitation zones. The analysis showed that erosion rates were reduced by one half in the high and intermediate zones from 1975 to 1990 as a result of the increased adoption of conservation tillage on more than half the land. Similarly soil erosion reduced by another 50% between 1990 and 2005 in the intermediate and high precipitation zones. In total the analysis showed a 75% reduction in soil erosion in the intermediate and high precipitation zones from 1975 to 2005. Reductions in the low precipitation zones were not as high showing a 50% decrease in erosion from 1975 to 2005. Kok et al. (2009) attributed the decrease in soil erosion to the following major changes:

1.) Decrease in the use of the moldboard plow
2.) Decrease in the number of tillage operations from 6-7 passes to 2-5 passes
3.) Decrease in the practice of burning stubble
4.) Increase in wheat yields yielding more residue
5.) Increase soil organic matter and surface residue cover
6.) Decrease in the use of summer fallow in the high precipitation zone
7.) Increase in conservation tillage, including no-till
8.) Conversion of most erodible land to the Conservation Reserve Program (CRP).

Although there has been wide-spread adoption of conservation or ‘reduced’ tillage practices throughout the region, no-till farming has not been widely adopted. Kok et al. (2009) estimated using drive-by windshield surveys and interviews that as of 2005 no-till was only being practiced on 10% of the land in both the high and intermediate precipitation zones.

Interviews with growers indicate that problems with excessive surface residues and weed control have limited the full adoption of no-till. The Kok et al. (2009) RUSLE2 analysis indicates that current soil erosion rates could decrease by 50% or more if no-till practices were widely adopted in all three precipitation zones.

Tier II Assessment GIS-Based RUSLE

Although at the hillslope-scale, a Tier I analysis provides a detailed assessment of specific tillage practices, it is impractical to apply this approach to large basins. A GIS-based RUSLE approach was used to estimate 30 m resolution erosion rates for large watersheds (see Fernandez et al. 2003; IDEQ 2003; Boll et al. 2001; Mitasova et al. 1996). The input requirements for this approach are a digital elevation model (DEM), 30 year average precipitation map, soil survey map with associated NRCS database, a land cover map, and a map delineating crop rotations and tillage practices.

L and S factors

The slope length (L) and slope steepness (S) factor are calculated directly from the DEM using the following equations:

$$L = (m+1)\left[\frac{A * d_{xy}}{22.13}\right]^{0.5} \tag{1}$$

$$S = \left[\frac{sin(b)}{0.0896}\right]^{0.6} \quad \text{for slopes} \geq 9\% \tag{2}$$

$$S = 10.8sin(b) + 0.03 \quad \text{for slopes} < 9\% \tag{3}$$

where *m* is a constant equal to 0.5, *A* is the upslope contributing area (number of cells including current cell), d_{xy} is the resolution of GIS map (should be no greater than 30 m), and b is the land slope (radians).

Following the approach of Fernandez et al. (2003) and recommendations by Renard et al. (1997) the upslope contributing area was limited to 120 m slope length (i.e. an upslope contributing area of 4 cells using a 30 m resolution DEM). The S factor equations used in this study were derived by McCool et al. (1993), for soils that are thawing, in a weakened state, and subjected primarily to surface flow (Renard et al., 1997).

K factor

The soil erodibility or K factor in RUSLE characterizes both the susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. K factors were obtained from county level (1:20,000) NRCS Soil Survey Geographic (SSURGO) data, where available, and taken from the state level (1:250,000) Soil Geographic (STATSGO) database if county level SSURGO maps were unavailable.

R factor

The rainfall-runoff erosivity or R factor characterizes the effect of raindrop impact and the amount and rate of runoff likely to be associated with rain (Renard et al. 1997). McCool (2001) developed a unique relationship for the R factor in the Northwestern Wheat and Range Region (NWRR). In these dryland farming regions the effect of soil freezing results in much higher R factors than would normally be calculated using the low intensity characteristic rainfall patterns found in this climate. The R factor is calculated directly from mean annual precipitation using the following equation.

$$R = -48 + 0.306P_r \tag{4}$$

where P_r is the mean annual precipitation in mm. In this analysis, 800 m resolution Parameter-elevation Regressions on Independent Slopes Model (PRISM) maps representing the mean annual precipitation for 1971-2000 were used to calculate the R factor.

C and P factors

One of the most challenging issues in conducting watershed scale analysis of soil erosion is acquiring information on crop rotations and tillage practices. Although there are detailed land use maps that capture the distribution of specific crops over large areas using remote sensing images, there are few maps which identify the specific cropping rotation for each field. In order to address this problem the National Agricultural Statistics Service (NASS) has begun an effort in the last few years of acquiring 56 m resolution land use maps that delineate specific crops for the entire US. These maps are called Cropland Data Layers (CDL) and could potentially be used to identify future crop rotations.

Although accurate crop rotation maps could improve future erosion predictions, there are few maps which delineate the type of tillage practices that are being used by the growers in the region. Since erosion prediction is highly sensitive to crop type and tillage type the accuracy of any erosion model is limited by how accurately the cropping and tillage practices are represented.

In this study we used the Kok et al. (2009) study to develop cropland (C Factor) and tillage practice (P Factor) maps for the NWRR. As described by Kok et al. (2009) dryland farming practices can be roughly lumped into precipitation zones: low (< 15 inches), intermediate (> 15 in and < 19 in), and high (> 19 inches). Growers in the low precipitation zone must use summer fallow to retain enough soil moisture to grow wheat every other year or every third year, depending upon the grower. Some growers in the intermediate zone still practice summer fallow, however summer fallowing is not required in the high precipitation zone. Crop yields are highest in the high precipitation zone which results in high surface residue after harvest.

Since the Kok et al. (2009) analysis used the RUSLE2 model which internally corrects for the effect of crop rotation and tillage practice on erosion, C factors were not calculated or supplied in the paper. The C factors for each suite of tillage operations were calculated by inverting RUSLE equation and solving for the C factor using the predicted erosion rate provided by the RUSLE2 analysis, see equations 5 and 6 below.

$$A = RKLSCP \tag{5}$$

$$C = \frac{A}{RKLSP} \tag{6}$$

where A is the average annual soil erosion in tons/ac/yr.

The R, K, L, and S factors were set to typical values for hillslopes in each region. The P factor was set to 0.91 following the recommendations of Fernandez et al (2003) and Boll et al (2001) which assumes farmers generally till on the contour rather than up and down the slope. Table 4 shows the equivalent C factors calculated for each cropping practice described by Kok et al. (2009). The weighted average C factor was calculated using the estimated percentage of each region using a specific cropping practice. As expected the C factors for each region are higher in 2005 than in 1975 as a result of the increased adoption of conservation practices.

Table 8. Equivalent C factors calculated cropping practices described by Kok et al. (2009).

Precip Zone	Year	Description	Percent Used	Erosion tons/ac	C factor
High	1975	Conventional Till H-1a	60	15.2	0.117
		Conventional Till H-1b	20	21.4	0.165
		Conventional Till H-1c	20	17.8	0.138
		Weighted Average		**17.6**	**0.136**
	1990	Conventional Till H-2a	50	13.4	0.103
		Reduced Till H-2b	35	5.4	0.041
		Reduced Till H-2c	15	6.7	0.052
		Weighted Average		**9.1**	**0.071**
	2005	Conventional Till H-3a	40	7.8	0.060
		Reduced Till H-3b	50	2.2	0.017
		No Till H-3c	10	0.9	0.007
		Weighted Average		**4.5**	**0.034**
Intermediate	1975	Conventional Till I-1a	80	12.0	0.104
		Conventional Till I-1b	10	12.9	0.112
		Conventional Till I-1c	10	14.9	0.129
		Weighted Average		**12.5**	**0.108**
	1990	Conventional Till I-2a	20	9.8	0.085
		Conventional Till I-2b	10	12.9	0.112
		Reduced Till I-2c	50	4.9	0.043
		Reduced Till I-2d	20	3.1	0.027
		Weighted Average		**6.2**	**0.054**
	2005	Reduced Till I-3a	30	1.8	0.015
		Reduced Till I-3b	50	4.0	0.035
		Reduced Till I-3c	10	4.5	0.039
		No Till I-3d	10	0.9	0.008
		Weighted Average		**3.1**	**0.027**
Low	1975	Conventional Till L-1a	75	8.9	0.111
		Conventional Till L-1b	25	8.7	0.108
		Weighted Average		**9.1**	**0.114**
	1990	Conventional Till L-2a	75	6.2	0.078
		Conventional Till L-2b	25	7.6	0.095
		Weighted Average		**6.2**	**0.078**
	2005	Conventional Till L-3a	75	5.4	0.067
		Reduced Till L-3b	15	2.5	0.031
		Reduced Till L-3c	10	1.8	0.022
		Weighted Average		**4.9**	**0.061**

Results

The GIS-based RUSLE model was applied to 14 watersheds within the Lower Snake River Basin, see Figure 13. The distribution of major land use classes is provided in Figure 14. This map was created from the 2009 NASS Cropland Data Layer. All forested, perennial grass, and scabland areas were excluded from the RUSLE analysis. It was assumed that all grassland would remain as a perennial grass. It is possible that some of this grassland may be farmed again in the future if the CRP contract is not renewed. Figure 15 shows the distribution of the K-factor within each of the study watersheds and Figure 16 shows the distribution of the mean annual precipitation for the region as defined by PRISM. Figure 17 shows the 30 m resolution average annual erosion map calculated using the weighted average C-factors for each precipitation zone as described in the previous section. As seen in Figure 17 the highest erosion rates tend to occur from agricultural areas located in the high precipitation zones (e.g. Clearwater watershed). Most of the average annual erosion rates are less 3 tons/ac in the western regions of the study area. Table 9 provides a summary of the predicted erosion by watershed. Figure 18 and Figure 19 provide a graphical distribution of the average erosion in million tons/year from each watershed and average annual erosion rates in tons/ac within each watershed. Although the RUSLE model predicted that the Palouse watershed contributes highest total erosion, both the Clearwater and Lower Snake-Tucannon watersheds have higher simulated erosion rates. Interestingly the highest erosion rates were predicted for the Little Salmon and Hell’s Canyon watershed however according to the land use map each of these watersheds contain less than 1 square mile of actively farmed agriculture area. Likely the little agricultural areas in this region have been improperly classified by the land use map.

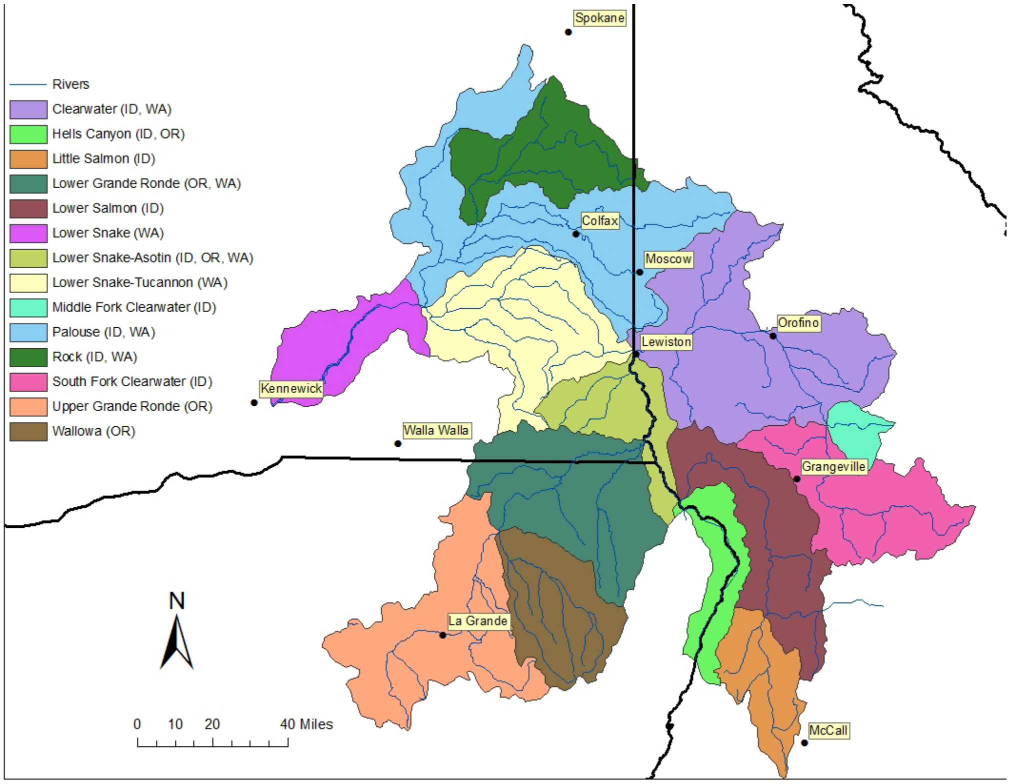

Figure 13. Agricultural watersheds within the Snake River Basin.

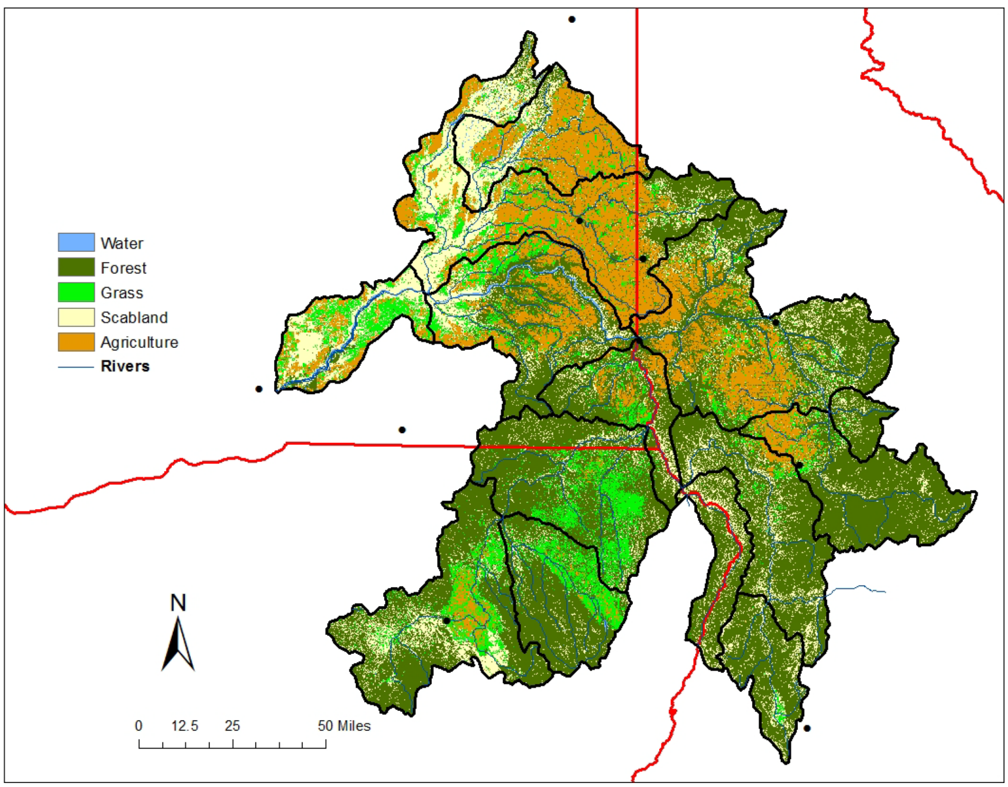

Figure 14. Distribution of major land uses within the study area.

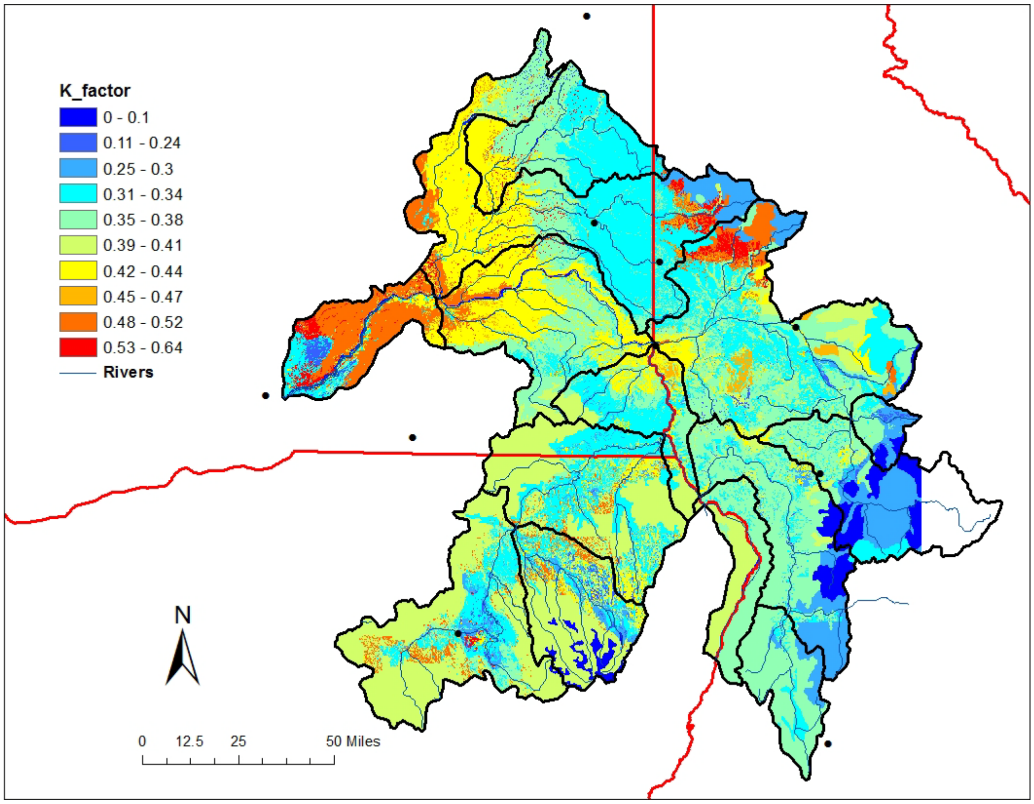

Figure 15. K-factor map developed from SSUGO and STATSGO databases.

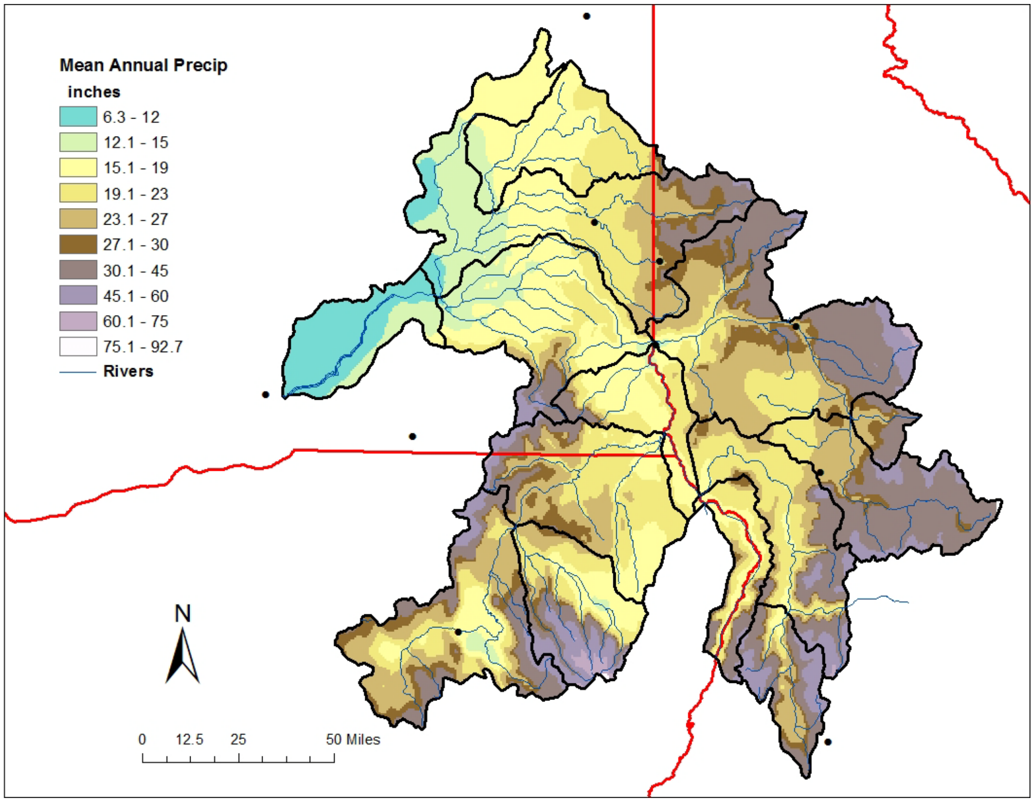

Figure 16. Mean annual precipitation (1971-2000) within the study area.

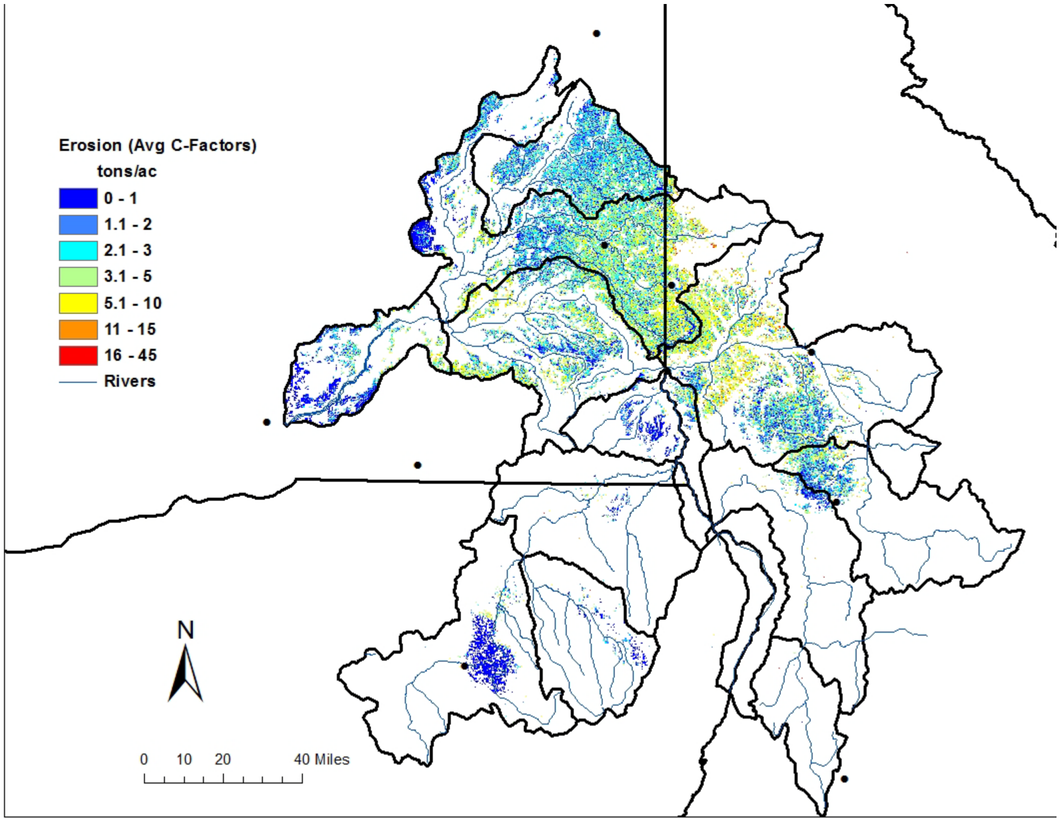

Figure 17. Average erosion rates (tons/ac) from agricultural areas within the study area.

Table 9. Average erosion rates and total erosion within each major watershed in the study area.

Name	HUC ID	Area (mi^2)	Pct Ag. Area	Avg. Erosion (tons/ac/yr)	Erosion (Million tons/yr)
Palouse (ID, WA)	17060108	2351	43.8%	3.3	2.17
Clearwater (ID, WA)	17060306	2319	25.6%	4.1	1.58
Lower Snake-Tucannon (WA)	17060107	1461	28.6%	3.4	0.91
Rock (ID, WA)	17060109	973	53.3%	2.5	0.84
South Fork Clearwater (ID)	17060305	1174	10.4%	2.8	0.22
Lower Snake (WA)	17060110	734	22.5%	1.9	0.20
Lower Snake-Asotin (ID, WA, OR)	17060103	713	11.5%	1.9	0.10
Lower Salmon (ID)	17060209	1232	3.0%	2.2	0.05
Upper Grande Ronde (OR)	17060104	1636	6.1%	0.8	0.05
Wallowa (OR)	17060105	935	2.2%	1.3	0.02
Lower Grande Ronde (OR, WA)	17060106	1506	0.7%	2.2	0.02
Little Salmon (ID)	17060210	589	0.1%	12.4	0.00
Middle Fork Clearwater (ID)	17060304	204	0.3%	4.7	0.00
Hells Canyon (ID, OR)	17060101	532	0.1%	7.5	0.00

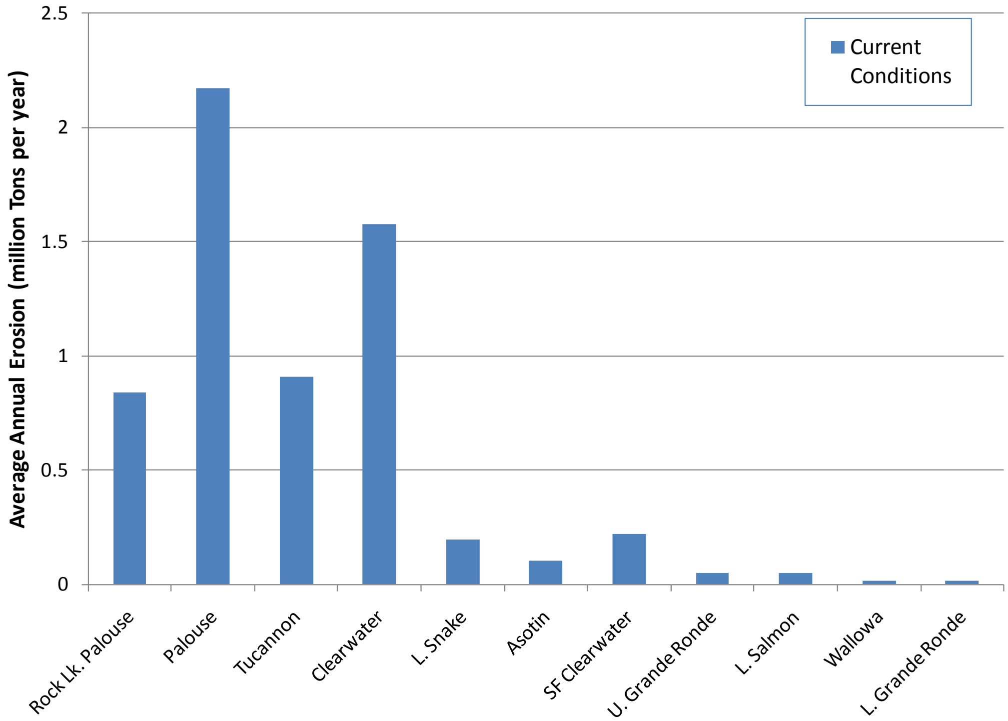

Figure 18. Average erosion (million tons per year) from agricultural areas within each watershed for current farming practices.

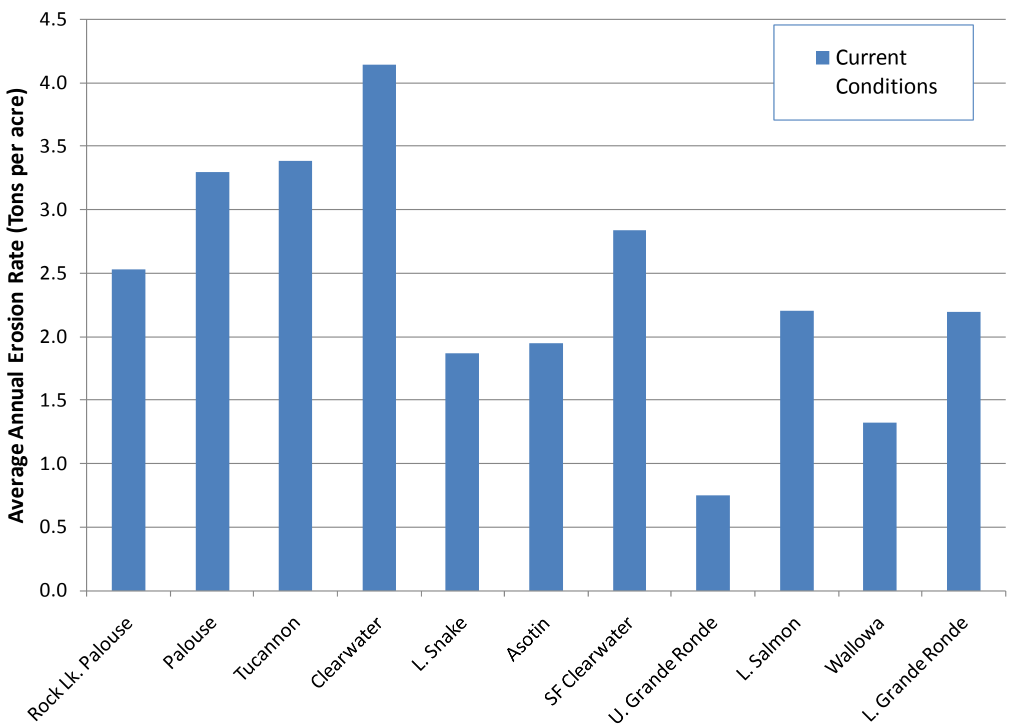

Figure 19. Average erosion rates (tons/ac/year) from agricultural areas within each watershed for current farming practices.

As a means of comparison the RUSLE model was used to predict soil for three hypothetical scenarios. Figure 20 and Figure 21 indicate the change in overall soil erosion if the entire agricultural area within each basin were farmed using conventional, reduced, and no till practices. The C-factors for this analysis were taken from the individual cropping scenarios for each precipitation zone as described by Kok et al. (2009), see Table 8. Similar to the Kok et al. (2009) study the high and intermediate precipitation zones are more sensitive to type of tillage practice than the low precipitation zones. Full adoption of no-tillage practices would drop the overall sediment load by 75% or more.

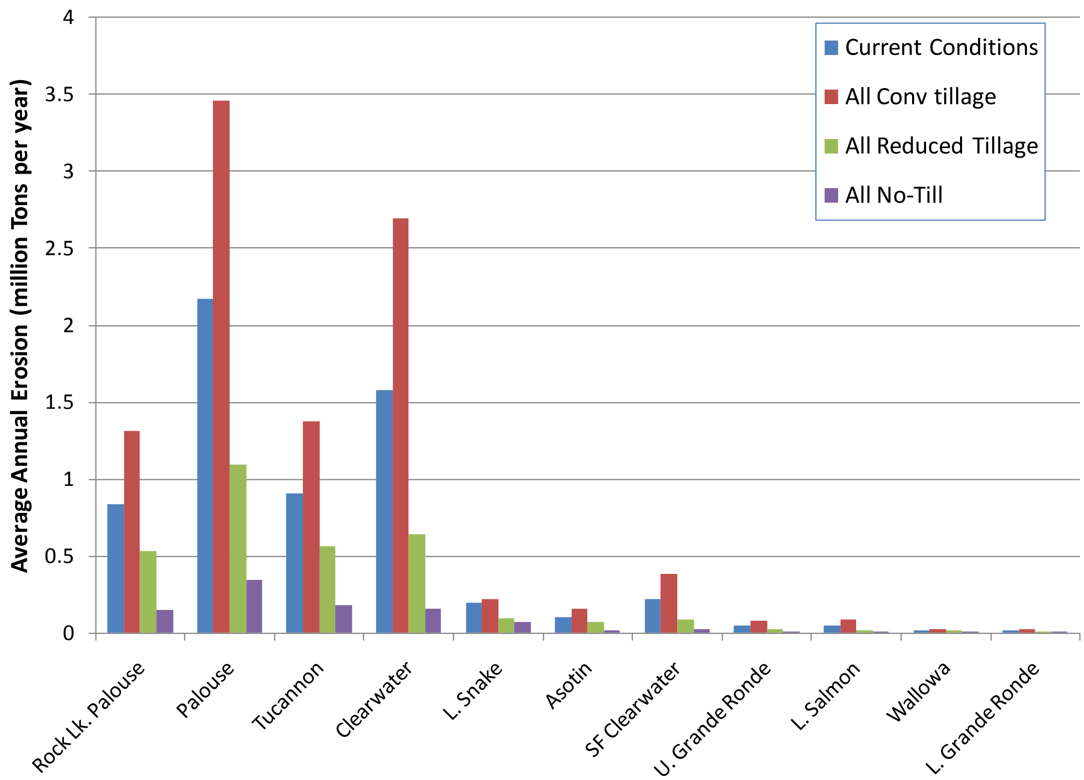

Figure 20. Comparison of average erosion (million tons per year) from agricultural areas within each watershed under current conditions versus a condition where all agricultural and was farmed using conventional, reduced, and no-till practices, respectively.

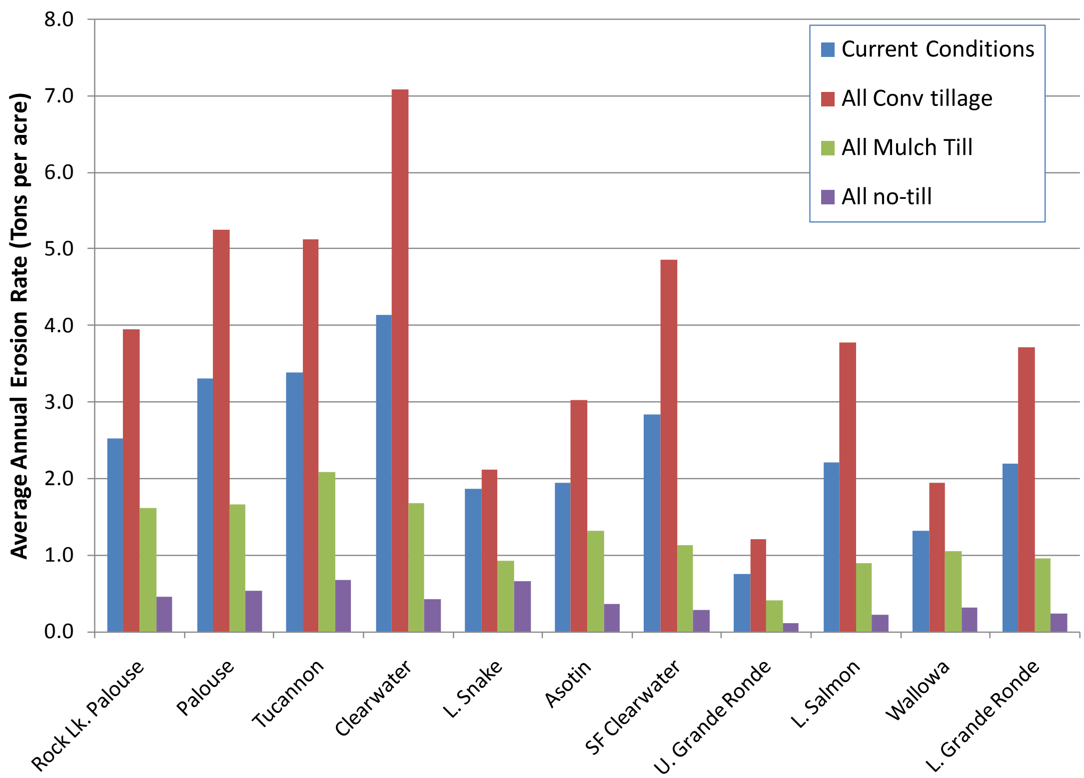

Figure 21. Comparison of average erosion rates (tons per acre per year) from agricultural areas within each watershed under current conditions versus a condition where all agricultural and was farmed using conventional, reduced, and no-till practices, respectively.

Sediment Yield

Since the primary interest of this project is to estimate sediment loading to the Lower Snake River Dams rather than gross erosion rates on the hillslopes, the total erosion predictions from the RUSLE approach were corrected to account for deposition and storage of sediment between the hillslope and watershed outlet. The standard approach for estimating the sediment yield uses a sediment delivery ratio (SDR). Vanoni (1975) developed an empirical relationship which related the SDR calculated from observed data across the US to watershed area. This relationship was described by the following equation.

$$SDR = 0.003567[\ln(A_{ws})]^2 - 0.060465[\ln(A_{ws})] + 0.295745 \quad (7)$$

where A_{ws} is the watershed area in square miles.

The sediment delivery ratio and sediment yield for each of the agricultural watersheds in the Lower Snake River Basin are presented in Table 10. It should be noted that the relationship developed by Vanoni (1975) was based on watershed ranging in size from 1 square mile to 300 square miles. The relationship between watershed area and SDR was assumed to be applicable to much larger watersheds in this study. Further research would be necessary to confirm this assumption.

Table 10. Sediment yield predicted for all watersheds using the sediment delivery ratio (Vanoni, 1975).

Name	HUC ID	Area (mi^2)	Erosion (Million tons/yr)	SDR	Sed Yield (Million tons/yr)
Palouse (ID, WA)	17060108	2351	2.17	0.041	0.09
Clearwater (ID, WA)	17060306	2319	1.58	0.041	0.07
Lower Snake-Tucannon (WA)	17060107	1461	0.91	0.045	0.04
Rock (ID, WA)	17060109	973	0.84	0.049	0.04
South Fork Clearwater (ID)	17060305	1174	0.22	0.047	0.01
Lower Snake (WA)	17060110	734	0.20	0.052	0.01
Lower Snake-Asotin (ID, WA, OR)	17060103	713	0.10	0.052	0.01
Lower Salmon (ID)	17060209	1232	0.05	0.046	0.00
Upper Grande Ronde (OR)	17060104	1636	0.05	0.044	0.00
Wallowa (OR)	17060105	935	0.02	0.049	0.00
Lower Grande Ronde (OR, WA)	17060106	1506	0.02	0.044	0.00
Little Salmon (ID)	17060210	589	0.00	0.055	0.00
Middle Fork Clearwater (ID)	17060304	204	0.00	0.075	0.00
Hells Canyon (ID, OR)	17060101	532	0.00	0.057	0.00

Validation to Observed Data

The decrease in soil erosion from the agricultural fields has lead to significant decreases in sediment load at the outlet of major rivers in the region, particularly in the Palouse region (see Brooks et al. 2010; Kok et al. 2009; McCool and Roe 2005; and Ebbert and Roe 1998). One of the longest records of flow and sediment concentration in the Palouse region has been acquired at a gage located on the Palouse River at Hooper, WA (USGS 13351000). Data from this gage has been used to document changes in sediment loading with time by Ebbert and Roe (1998). In order to update the Ebbert and Roe (1998) analysis we acquired streamflow and sediment concentration data for the Hooper gage and organized the data into three major time periods: 1961-1971, 1992-1997, and 1998-2010. Figure 22 shows the streamflow versus suspended sediment concentration as a log-log scatter plot. As seen in the figure, there is a noticeable shift in relationship between suspended sediment concentration and streamflow over time.

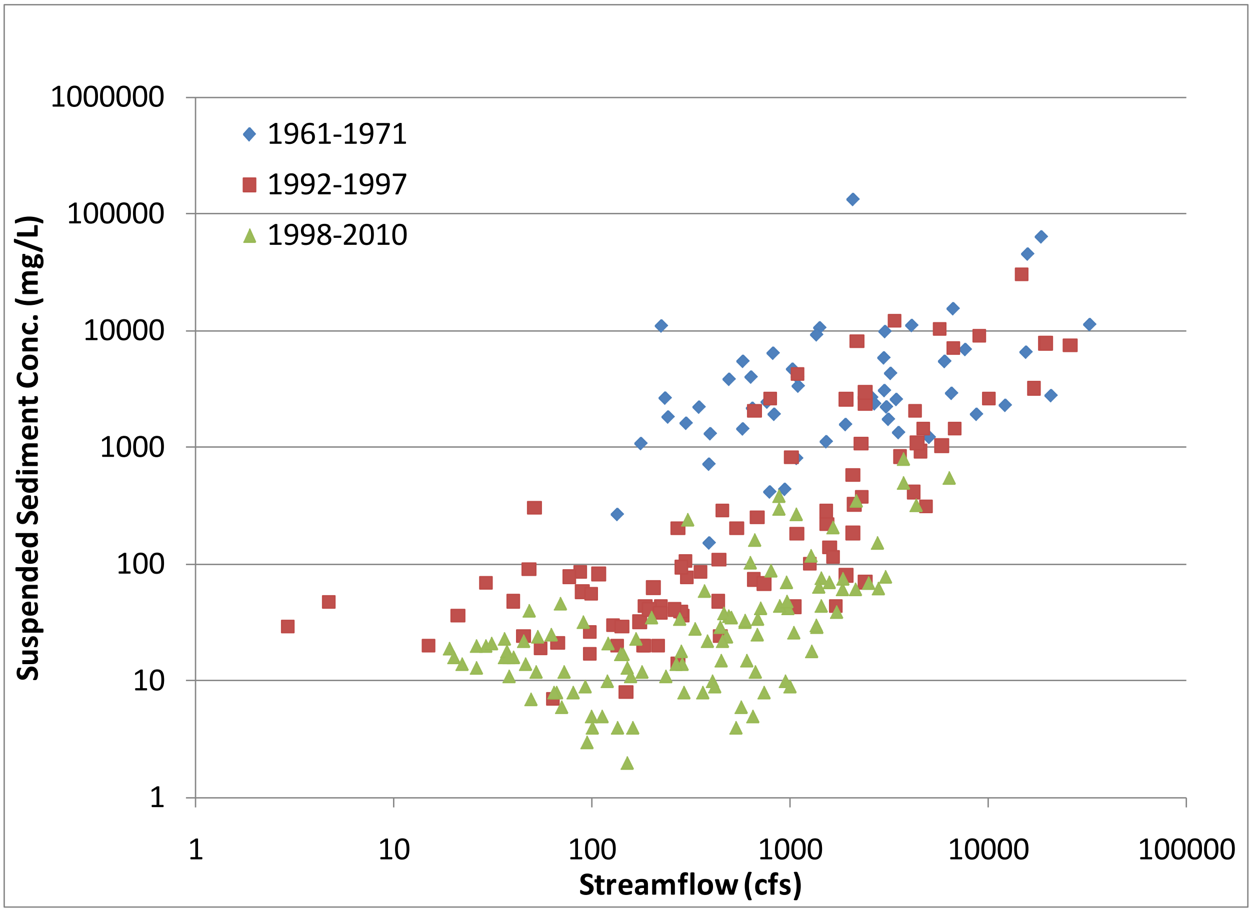

Figure 22. Observed streamflow versus observed suspended sediment concentration measured on the Palouse River at Hooper, WA.

Ebbert and Roe (1998) estimated that in average annual sediment load at the Hooper gage on the Palouse river from 1993-1996 was 1.4 tons/ac-ft. According to the streamflow data collected at the Hooper gage the average annual streamflow volume is 432,000 ac-ft/yr. This means that the average annual sediment load in the early 1990s was approximately 0.6 million tons per year. According to the analysis in this study the average annual sediment yield from the agricultural areas in the Palouse basin is currently 0.09 million tons of sediment per year. Assuming that the majority of the sediment derived from agricultural sources this implies that the sediment yield has decreased by 68% since the early 1990s. Although it is difficult to quantify, Figure 22 generally indicates there has been a 50% decrease in average sediment concentration over a wide range of observed streamflows at the Hooper gage since the early 1990s. Although the current sediment yield estimates are largely based on a extrapolated SDR values, the magnitude of sediment load estimated by the GIS-based RUSLE approach is roughly corroborated by the observed data at the Hooper gage.

Over the last 10 years sediment load has also been measured using detailed event-based water sampling in the Paradise creek watershed located near Moscow, ID in the high precipitation zone of the Palouse watershed. The average annual sediment load from 2002 to 2008 from this 19.9 sq. mil watershed was measured at 860 tons per year (Brooks et al. 2010). During this time nearly all farmers have been using reduced tillage practices. The predicted erosion rate for this watershed using the GIS-based RUSLE analysis is 8,800 tons per year. According to the Vanoni (1975) relationship the SDR for this watershed is 0.15. Multiplying the average annual erosion by the SDR results in an average annual sediment yield of 1320 tons per year. This predicted sediment yield value is roughly 50% over the sediment yield observed. This over-prediction could possibly be due to the fact that the 7 year average sediment yield does not include an extreme flood event. The RUSLE provides 30 year average erosion estimates and therefore would incorporate more extreme events. Brooks et al. (2010) also calculated sediment load for Paradise creek from three day per week grab samples taken at the outlet of the watershed from 1988 to the present. Using these data it was estimated that the extreme 1996 flood year carried 10,000 tons of sediment. By including this year in the analysis the average annual observed sediment yield is 1900 tons per year which is higher than the sediment yield predicted by the GIS-based RUSLE approach. From this analysis we feel confident that the sediment yield predictions provided by the GIS-based RUSLE approach are reasonable.

Particle Size Assessment

Of particular importance in this project is quantifying the relative sediment distribution of the soil delivered to the Lower Snake River Dams. Since the majority of the sediment deposited in the Snake River is sand it is particularly important to assess the fraction of sand delivered by each watershed to the Snake River from the agricultural areas. From basic erosion mechanics it is well understood that the larger particles (i.e. sands) have a faster settling velocity than the finer particles (i.e. clays and silts) and therefore sands will tend to deposit preferentially in a water column sooner than silts and clays. Hillslopes having a large toe slope will tend to have deposition which will result in an ‘enrichment’ in the proportion of silts and clays and a decrease in the proportion of sands. The proportion of sand in steep hillslopes which do not experience deposition should theoretically never be greater than the fraction of sand in the detached sediment. Knowing this it then it is reasonable to assume that the portion of sand in the eroded sediment will be no greater than the fraction of sand in the original soil. Using this assumption we estimated the maximum percent sand in the eroded sediment as the average sand content of the agricultural soils in the watershed. Figure 23 shows the distribution of percent sand in all the agricultural watersheds in the Lower Snake River Basin. Comparing Figure 23 with Figure 14 it is clear that the agricultural soils have a much lower sand content then the non-agricultural soils. Nearly all agricultural soils in the major contributed agricultural watersheds are composed of less than 20% sand. Figure 24 shows that the sand content of the surface soil horizons in all agricultural regions are less than the sand content for the non-agricultural regions. It is also important to remember that the sand content in these figures are for the surface soils. Most forested soils are covered with an ash layer and the soil horizons beneath this ash layer are typically much greater. Agricultural soils in the study area are typically much deeper and rather than the sand content increasing with depth, the clay content will more often increase with depth below the soil surface.

By assuming that the proportion of sand in the sediment delivered to the outlet does not decrease due to preferential deposition Table 11 shows the total sand delivered from agricultural areas from each of the major watersheds in the Lower Snake River Basin. As discussed above this is likely an over-estimate of the actual sand delivered to the outlet since the sand will tend to settle out more rapidly than the silt and clay as it moves to the watershed outlet. We estimated the likely over-prediction of sediment using the WEPP model at typical slopes within the low, intermediate, and high precipitation zones. The deposition of sediment is more likely on toe slopes below steep sections of the hillslope. We used the WEPP model to predict the erosion and deposition for a three piece hillslope where the upslope, mid slope and toe slope steepness were 5%, 35%, and 5% respectively. Each segment length was set at 328 ft (100 m). The 30 year simulation was based on a Palouse soil with a reduced tillage operation and a winter wheat, spring barley, pea rotation and a high precipitation climate (Moscow, ID). The sand content of the original soil was 9%. The sand content in the soil delivered to the outlet of the hillslope was reduced by half this at 5.4%. This reduction in sand content was similar for a range of soil types and cropping practices. Overall it is clear that the agricultural areas contribute mostly silts and clays to the Snake River.

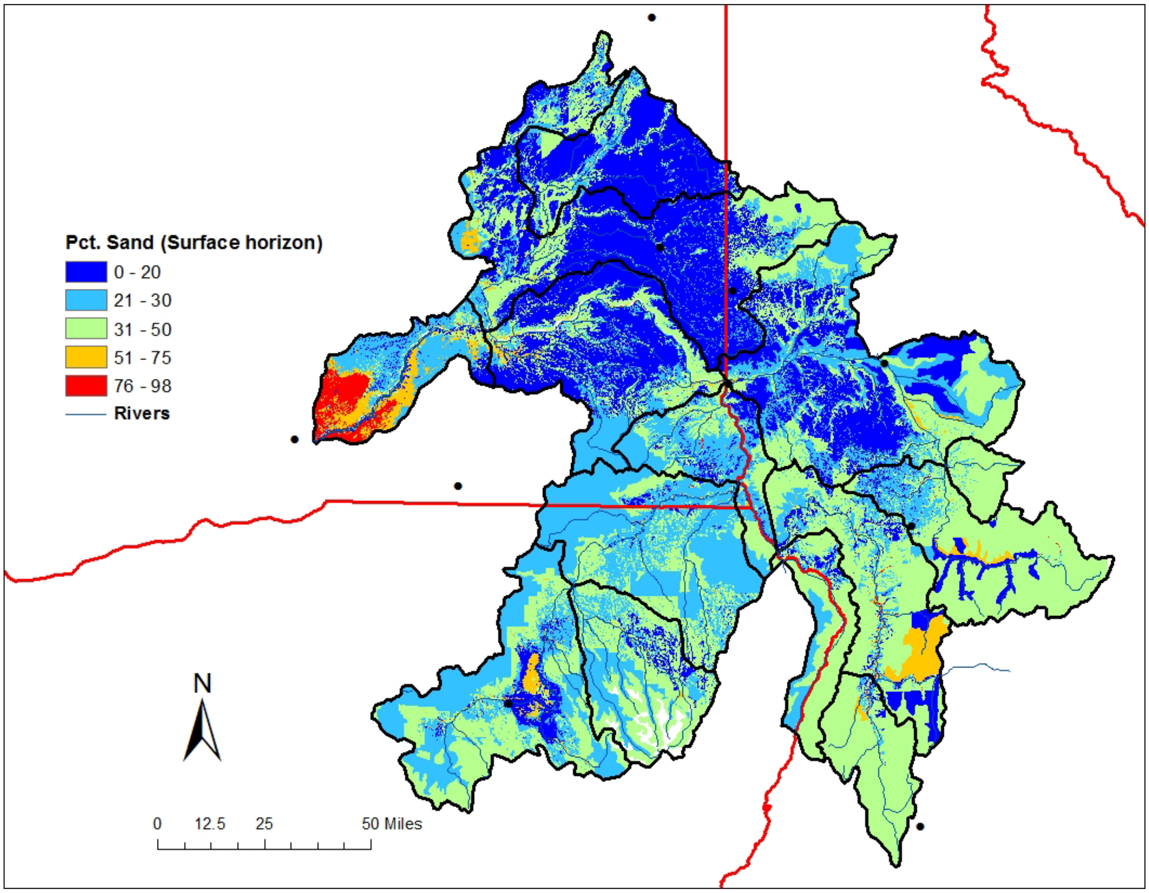

Figure 23. Percent sand content in the surface soil horizon taken from the SSURGO and STATSGO databases.

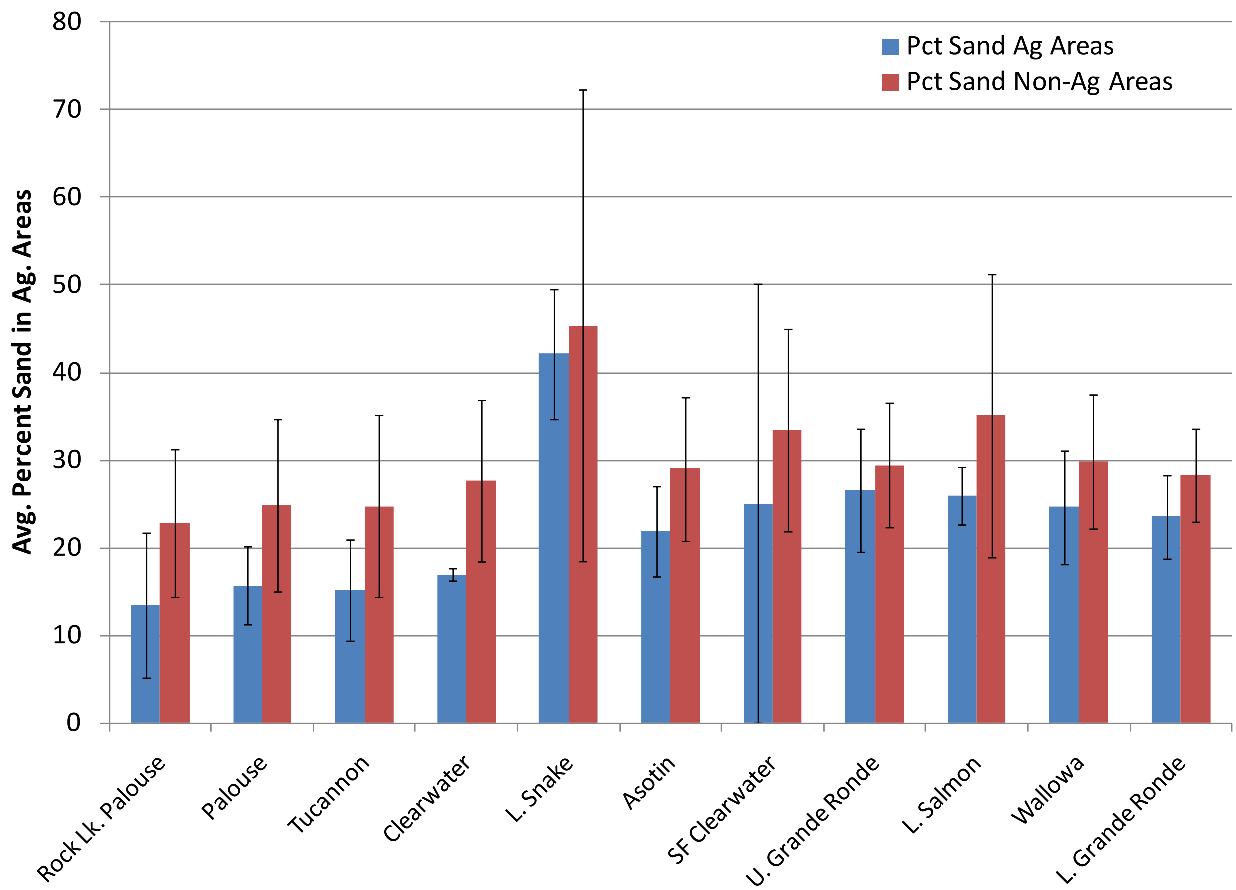

Figure 24. Average percent sand content of the surface soil horizon for both agricultural and non-agricultural areas of the major watersheds in the Lower Snake River Basin. Error bars on each column represent one standard deviation.

Table 11. Total sand delivered from agricultural areas. Note this numbers should be considered a maximum value since preferential deposition of sand is neglected.

Name	HUC ID	Area (mi^2)	Total Sediment Yield (million tons/yr)	Mean % Sand	Total Sand (million tons/yr)
Palouse (ID, WA)	17060108	2351	0.09	15.72	1.4E-02
Clearwater (ID, WA)	17060306	2319	0.07	16.93	1.1E-02
Lower Snake-Tucannon (WA)	17060107	1461	0.04	15.15	6.1E-03
Rock (ID, WA)	17060109	973	0.04	13.49	5.5E-03
South Fork Clearwater (ID)	17060305	1174	0.01	25.03	2.6E-03
Lower Snake (WA)	17060110	734	0.01	42.12	4.3E-03
Lower Snake-Asotin (ID, WA, OR)	17060103	713	0.01	21.86	1.2E-03
Lower Salmon (ID)	17060209	1232	0.00	25.98	6.2E-04
Upper Grande Ronde (OR)	17060104	1636	0.00	26.58	5.6E-04
Wallowa (OR)	17060105	935	0.00	24.69	2.1E-04
Lower Grande Ronde (OR, WA)	17060106	1506	0.00	23.55	1.6E-04
Little Salmon (ID)	17060210	589	0.00	35.19	5.3E-05
Middle Fork Clearwater (ID)	17060304	204	0.00	35.31	4.4E-05
Hells Canyon (ID, OR)	17060101	532	0.00	35.96	2.7E-05

3.5 Watersheds with Significant Sediment Yield Potential

Although considerable achievements have occurred with respect to implementing agricultural BMPs in the basin, Figure 25 and Figure 26 indicate there is more work to do. The upper panel in Figure 25 shows farming to the very edge of the waterway while Figure 26 shows a similar practice along a road-side ditch.

Figure 25. Examples of ongoing agricultural practices contributing to sediment delivery.

Figure 26. Ephemeral gullies leading to surface erosion connections to nearby waterway.

Table 11 in the previous section contained the amount of sand coming from each agricultural subbasin in the study area. Sand, by most standard definitions, has particle sizes ranging from 62.5 microns to 2,000 microns (2 mm). This is approximately equivalent to sieve designations of #230 (63 microns) and #10 (2 mm). In examining 24 sediment core samples from the confluence area of the Snake and Clearwater River collected by the USGS and provided to WSU by the USACE, it was found that on average, less than 7% of the soil was finer than a #200 sieve (75 microns). In other words, over 93% of the soil was classified as sand. In fact, approximately 64% could be classified as medium to coarse sand (retained on #70 sieve or larger). Given the relatively low % sand fractions and loads in Table 11, meaningful reduction in the sizes of materials settling in the pool may be difficult to achieve. Nevertheless, the next section of this report demonstrates how much erosion could be reduced even if the particles are finer than those of primary concern.

In terms of total sediment load, it appears that the Palouse is still the most significant contributor in terms of total load. This may be a concern downstream of the confluence in the lower Snake River basin but is not a concern to Lower Granite pool. The largest contributor to this segment is the Clearwater River basin (including the Potlatch and Lapwai subbasins). However the percent sand in this watershed is relatively low.

3.6 Evaluation of Agricultural Sediment Reduction Measures

Adoption of even modest practices such as that shown in Figure 27 will help reduce erosion and delivery of fine sediments in the study area. Wider adoption of no-till (or direct seeding) as illustrated in Figure 28 would have a more profound impact. The Tier I WEPP analysis that follows helps to quantify potential impacts.

Figure 27. Conventional tillage surrounded by mulch till and stubble.

Figure 28. Direct seed practice.

Tier I Analysis using WEPP:

The Tier I, hillslope-scale analysis of Kok et al. (2009) was extended in this project to investigate the effects of specific management practices on both sediment detachment and delivery of sand, silt, and clay particle size classes. The WEPP model was used to examine these sediment delivery processes. WEPP management files were parameterized using the crop rotations and tillage practices described by Kok et al. (2009) for the low, intermediate, and high precipitation zones. The WEPP model was used to simulate 30 year average annual soil detachment (i.e. erosion) and sediment delivery (i.e. yield) for typical soils and climates for each of these regions, see Figure 29. The characteristic hillslope chosen for this analysis had three individual 100 m linear segments having slope steepness of 10%, 30%, and 5% for up-slope, mid-slope, and toe-slope sections, respectively. An Athena silt loam was used in the low precipitation zone and a Palouse silt loam soil was used for the intermediate and high precipitation zone scenarios. The CLIGEN model, a stochastic weather generator model used in the WEPP model, was used to develop 30 year daily weather files for each region. Weather files were developed for Harrington, WA, Pomeroy, WA, and Moscow, ID to represent climates in the low, intermediate, and high precipitation zones, respectively. The mean annual precipitation amounts at Harrington, WA, Pomeroy, WA, and Moscow, ID are 13, 16, and 25 inches, respectively.

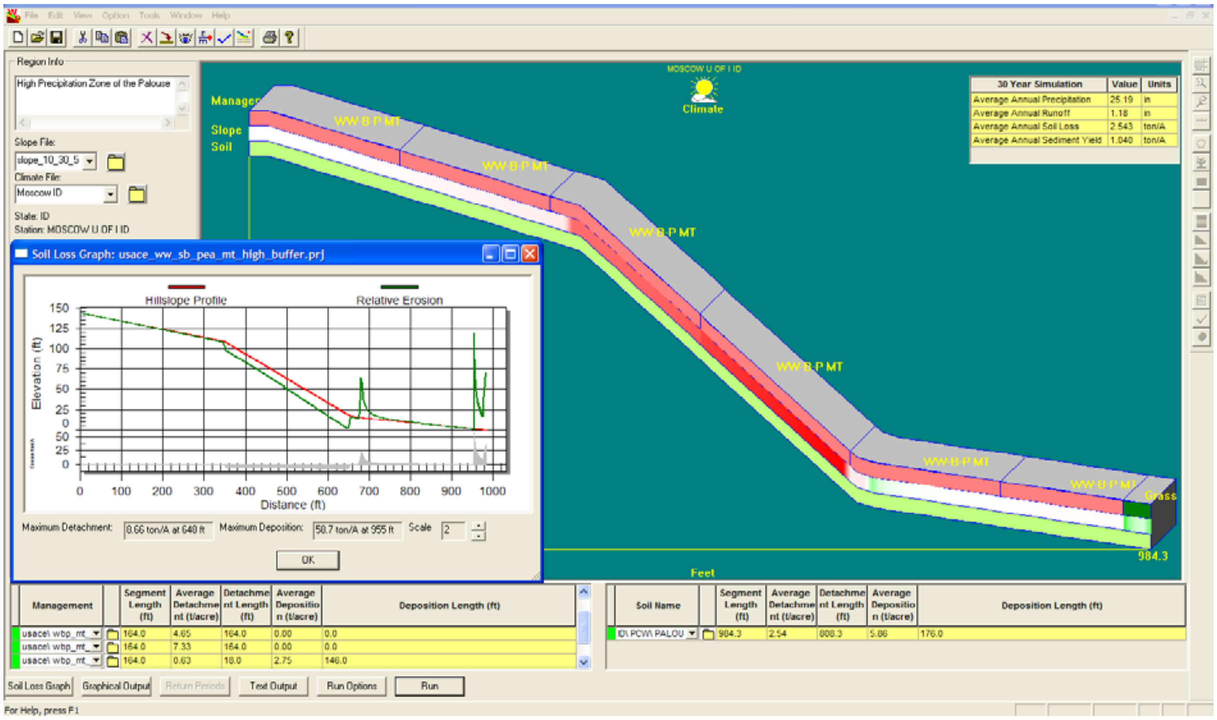

Figure 29. A screenshot of the WEPP model. Notice the exaggerated hillslope profile indicating the relative location of deposition and scour.

Overall soil detachment (i.e. erosion) rates simulated by the WEPP model for each of the crop-tillage scenarios were similar in magnitude and had the same relative trends as those determined using the RUSLE2 model by Kok et al. (2009), see Table 12. The greatest detachment rates (9.56 tons/acre) occurred with conventional tillage practices in the high precipitation zone. Conversion from conventional tillage to reduced or mulch tillage in the high precipitation zone decreases erosion rates to 2.51 t/ac. No-till practices reduced detachment rates in the high precipitation zone down to 0.39 tons/ac which is very close to the detachment rates for a perennial grass, 0.28 t/ac.

The amount of soil delivered at the end of the hillslope can be substantially less than the amount of soil detached along the hillslope. This is particularly true for highly eroding slopes. For example, the overall amount of sediment delivered at the end of the slope (i.e. to a stream network) for conventional tillage practices in the high precipitation zone is roughly a third, 3.27 t/ac, of the amount of sediment detached along the slope, 9.56 t/ac. In contrast there is very little difference between overall sediment detached and delivered for no-till practices, see Table 12.

Table 12. Sediment detachment and delivery by particle size class for each of the crop-tillage scenarios described by Kok et al. (2009).

Precip Zone	Rotation	Tillage	Total Detached Sediment (tons/ac)	Total Delivered Sediment (tons/ac)	Detached Sand (tons/ac)	Delivered Sand (tons/ac)	Detached Silt (tons/ac)	Delivered Silt (tons/ac)	Detached Clay (tons/ac)	Delivered Clay (tons/ac)
High	WW–SG–P	Conv.	9.56	3.27	1.08	0.18	6.47	2.30	2.01	0.79
	WW–SG–P	Reduced	2.51	1.62	0.28	0.11	1.70	1.14	0.53	0.36
	WW–SG–P	No-Till	0.39	0.39	0.04	0.04	0.27	0.27	0.08	0.08
	CRP/Grass	None	0.28	0.28	0.03	0.03	0.19	0.19	0.06	0.06
Interm.	WW–SB–P	Reduced	0.55	0.37	0.06	0.04	0.37	0.25	0.12	0.08
	WW–SB–F	Reduced	1.93	1.37	0.22	0.15	1.30	0.93	0.41	0.29
	WW–SB–CF	Reduced	1.90	1.30	0.21	0.14	1.28	0.88	0.40	0.28
	WW–SG–P	No-Till	0.07	0.05	0.01	0.01	0.05	0.03	0.02	0.01
	CRP/Grass	None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low	WW–F	Conv.	3.89	2.34	0.66	0.35	2.53	1.56	0.70	0.43
	WW–SB–CF	Reduced	2.77	1.86	0.47	0.27	1.80	1.24	0.50	0.35
	WW–F	Reduced	1.19	0.63	0.20	0.09	0.77	0.42	0.22	0.12
	CRP/Grass	None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WW- winter wheat, SG – spring grain (e.g. barley or wheat), P – peas, SW – spring wheat, CRP – conservation reserve program, F – tilled fallow, CF – chemical fallow, L – lentils.

When looking at the actual sand, silt, and clay particle size classes it is clear that the majority of the soil delivered to the end of a slope is composed of silt-sized particles in all precipitation zones. Sand sized particles are not only a small part of the original soil (11.3% for a Palouse silt loam, 16.9% for an Athena silt loam) these larger particles preferentially deposit faster than the silt- and clay-sized particles and therefore the sediment delivered at the end of the hillslope is even further enriched with silt and clay sized particles. As seen in Table 12, although soil detachment rates for conventional tillage in the high precipitation zone are 9.56 t/ac, the detachment rate for the sand sized particles is only 1.08 t/ac. In addition, of the 1.08 t/ac of sand only a tenth, 0.18 t/ac, is delivered to the stream at the end of the slope.

As described by Kok et al. (2009) the most widespread soil conservation practice adopted in the Palouse region has been the conversion from conventional tillage to reduced or mulch tillage. Three other relatively common management practices used in the region are conversion of erosive cropland to perennial grass through the conservation reserve program (CRP), installation of gully plugs in the high precipitation zone, and to a lesser extent grass buffer strips along streams. Gully plugs are small catch basins having a perforated riser pipe that intercepts surface runoff and pipes the water to a stream or grass buffer. The purpose of the gully plug is to intercept the runoff before flow velocities can increase and generate a gully. Gully plugs are typically installed 1/3rd of the distance from the top of the slope above the steepest section of the slope. The effectiveness of each of these practices was analyzed for each precipitation zone using the WEPP model. Table 13 summarizes the reduction in sediment load for each management practice in the high precipitation zone for the various crop-tillage practices.

As seen in this Table 13, the reduction in overall delivered sediment load for a typical hillslope under conventional tillage in the high precipitation zone with a 30 foot grass buffer, 1.99 t/ac, is not quite as effective as adopting reduced tillage practices over the entire hillslope, 1.62 t/ac. However notice that the buffer strip was more effective at reducing the delivery of sand-sized particles, 0.07 t/ac, than converting to reduced tillage practices alone, 0.11 t/ac. The last two columns in Table 13 identify the percent reduction in overall sediment delivered sediment and the sand size class. As seen in this table, adding a 30 ft grass buffer reduces the overall delivered sediment load by 39.3% but reduces the delivered sand fraction by 61.9%.

Adding a gully plug to a hillslope is more effective under conventional tillage than a 30 ft buffer strip alone at reducing overall sediment load (41.1% reduction) however a buffer strip is more effective at reducing the delivery of sand sized particles. As seen in Table 13, the WEPP model predicted only a 24.9% reduction in delivered sand with a gully plug as opposed to a 61.9% reduction delivered sand with a grass buffer strip. Notice that the trend in differences between the effectiveness of a 30 ft grass buffer and a gully plug are very similar if the field is currently being farmed under reduced tillage or no tillage.

Table 13. Assessment of the effectiveness of CRP, 30 ft grass buffer, gully plugs, and conservation tillage at reducing the detachment and delivery of sand, silt, and clay sized particles to streams in the high precipitation zone using the WEPP model.

Tillage	BMP	Total Detached Sediment (tons/ac)	Total Delivered Sediment (tons/ac)	Detached Sand (tons/ac)	Delivered Sand (tons/ac)	Detached Silt (tons/ac)	Delivered Silt (tons/ac)	Detached Clay (tons/ac)	Delivered Clay (tons/ac)	Reduction in Delivered sediment (pct)	Reduction in Delivered Sand (pct)
Conv.	None	9.56	3.27	1.08	0.18	6.47	2.30	2.01	0.79		
	30’ Buffer	9.26	1.99	1.05	0.07	6.27	1.42	1.95	0.50	39.3%	61.9%
	Gully Plug	4.01	1.93	0.45	0.14	2.71	1.36	0.84	0.43	41.1%	24.9%
Reduced	None	2.51	1.62	0.28	0.11	1.70	1.14	0.53	0.36		
	30’ Buffer	2.54	1.04	0.29	0.04	1.72	0.75	0.54	0.25	35.8%	61.8%
	Gully Plug	0.35	0.31	0.04	0.03	0.24	0.21	0.07	0.07	81.0%	73.6%
No-Till	None	0.39	0.39	0.04	0.04	0.27	0.27	0.08	0.08		
	30’ Buffer	0.40	0.35	0.05	0.03	0.27	0.25	0.08	0.07	10.7%	37.2%
	Gully Plug	0.04	0.04	0.01	0.00	0.04	0.03	0.01	0.01	89.3%	89.2%
CRP	Grass	0.28	0.28	0.03	0.03	0.19	0.19	0.06	0.06		

The enrichment of clay sized particles is greatest with conventional tillage practices in the high precipitation zone, see Table 14. The deposition of sand sized particles leads to an enrichment of clay sized particles in the delivered sediment. Table 14 identifies the percent sand, silt, and clay in the delivered sediment for a Palouse silt loam soil hillslope composed of 11.3% sand, 67.7% clay, and 21.1% clay. Under conventional tillage practices alone the amount of sediment delivered to the toe slope exceeds the transport capacity of the surface runoff which leads to deposition. This topographic effect alone leads to enrichment of clay from 21.1% in the detached sediment to 24.1% in the delivered sediment. In contrast, the deposition of sand reduces the portion of sand from 11.3% in the detached sediment to 5.6% in the delivered sediment. Adding a 30 ft grass buffer at the end of the slope reduces the proportion of sand in the delivered sediment even further down to 3.5%. The enrichment of clay and depletion of sand in the delivered sediment is not as important in reduced tillage and no-tillage fields since the overall sediment load is often less than the transport capacity of the water resulting in less deposition of sediment.

As expected the most effective management technique is conversion of the entire field to perennial grass (i.e. CRP). Conversion to CRP essentially eliminates erosion in the intermediate and low precipitation zones and delivers very negligible sand in the high precipitation zone, see Table 12 and Table 14.

The selection of the appropriate management practice must include an economic analysis which was beyond the scope of this project. However it should be noted that these WEPP simulations support the findings of Kok et al. (2009) and agree with current trends in overall sediment load recorded at the Hooper, WA stream gage station that the conversion to reduced tillage and no-tillage practices alone is very effective a reducing the delivery of sediment to streams. Installation of buffer strips, conversion to CRP, and, to a lesser extent, installation of gully plugs all take land out of production and therefore would not be as attractive an option for regional farmers without economic incentives.

Table 14. Particle size breakdown of detached and delivered sediment for a Palouse Silt Loam soil (11.3% sand, 67.7% silt, 21.1% clay) in the high precipitation zone.

Tillage	BMP	Total Detached Sediment (tons/ac)	Total Delivered Sediment (tons/ac)	Delivered Sand (%)	Delivered Silt (%)	Delivered Clay (%)
Conventional	None	9.56	3.27	5.6%	70.3%	24.1%
	30 ft Grass Buffer	9.26	1.99	3.5%	71.4%	25.1%
	Gully Plug	4.01	1.93	7.1%	70.6%	22.4%
Reduced/Mulch	None	2.51	1.62	7.1%	70.4%	22.5%
	30 ft Grass Buffer	2.54	1.04	4.2%	72.0%	23.7%
	Gully Plug	0.35	0.31	9.9%	68.7%	21.4%
No-Till	None	0.39	0.39	11.2%	68.0%	21.1%
	30 ft Grass Buffer	0.40	0.35	7.8%	71.7%	20.7%
	Gully Plug	0.04	0.04	11.3%	67.8%	21.0%
CRP	Perennial grass	0.28	0.28	10.6%	68.1%	21.1%

Importance of Extreme Events:

The delivery of sediment in natural systems is dominated by extreme events. This has been described early in the report with observed data at the Hooper, WA stream gage station and has been observed in sediment cores extracted in the backwater pools above the dams. It has also been visually observed in location such as the floodplain of Tenmile Creek (see Figure 30) where the finer grain sediments and soils have been totally washed away leaving only larger gravels and cobbles. In this section we quantify the effects of management practices on the frequency of sediment delivery events using the WEPP model.

Figure 30. Sediment scour on Tenmile Creek as a result of flooding.

The importance of extreme events was captured by analyzing daily output over a 30 year simulation using the WEPP model. Figure 31 presents a relationship between the percent of storm events and the total 30 year delivered sediment load for a single hillslope under conventional tillage practices in the high precipitation zone. Storm events were defined as any day in which the model simulated sediment leaving the hillslope. As seen in Figure 31, over half the total sediment load from this hillslope was delivered in only 10% of the events. Nearly all the sediment load, 95%, was delivered by only 30% of the events.

Adopting reduced tillage practices reduces the overall magnitude of events and increases the number of years where no erosion will occur. Figure 32 provides a distribution of annual sediment loads for conventional, reduced, and no-tillage practices for a single hillslope located in the high precipitation zone. Figure 32 indicates that the WEPP model predicted that 3 out of 30 years no sediment was delivered from a hillslope under conventional tillage in the high precipitation zone. In addition, Figure 32 shows for 15 out of the 30 years the overall delivered sediment load for conventional tillage was between 0-100 lbs/ft. During one out of the 30 years the delivered sediment load for conventional tillage was as high as 1300 lb/ft. In contrast to the conventional tillage reduced tillage increased the number of years without any delivery of sediment from 2 out of 30 years with conventional tillage to 14 out of 30 years. For no-tillage the model indicated that 23 out of 30 years had no delivered sediment. The highest delivered annual sediment load for reduced tillage and no-tillage was 1000 lb/ft and 300 lb/ft, respectively.

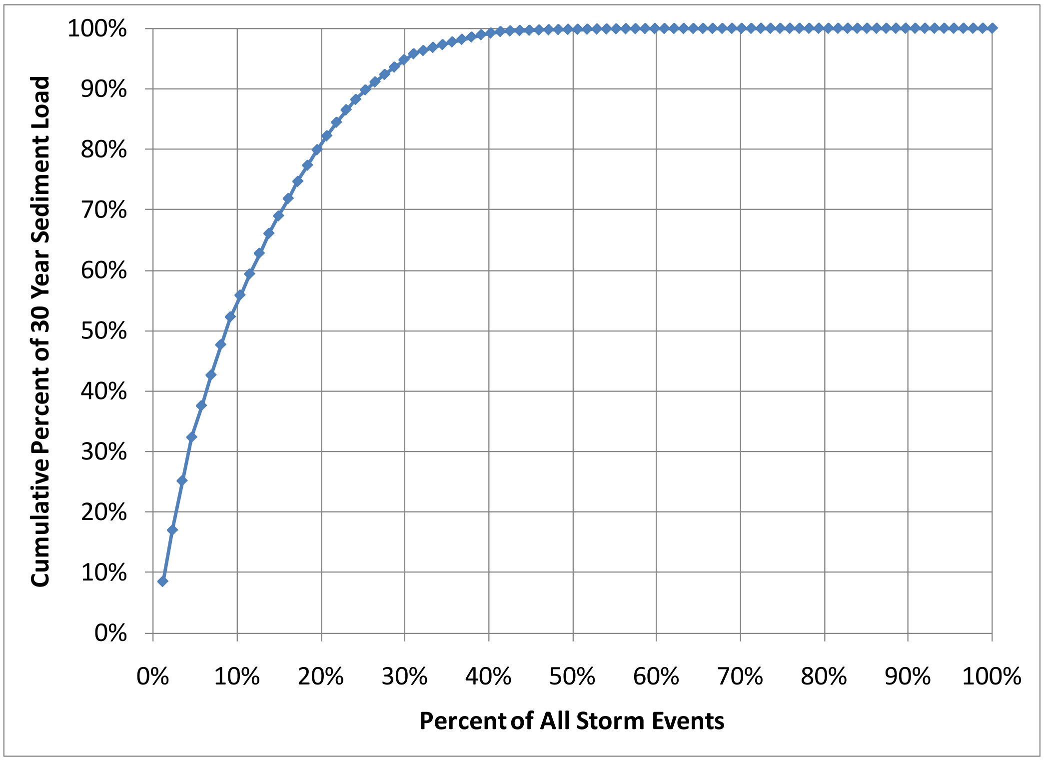

Figure 31. Proportion of the average annual sediment load versus percent of all storm events as predicted by the WEPP model for conventional tillage practices in the high precipitation zone of the Palouse.

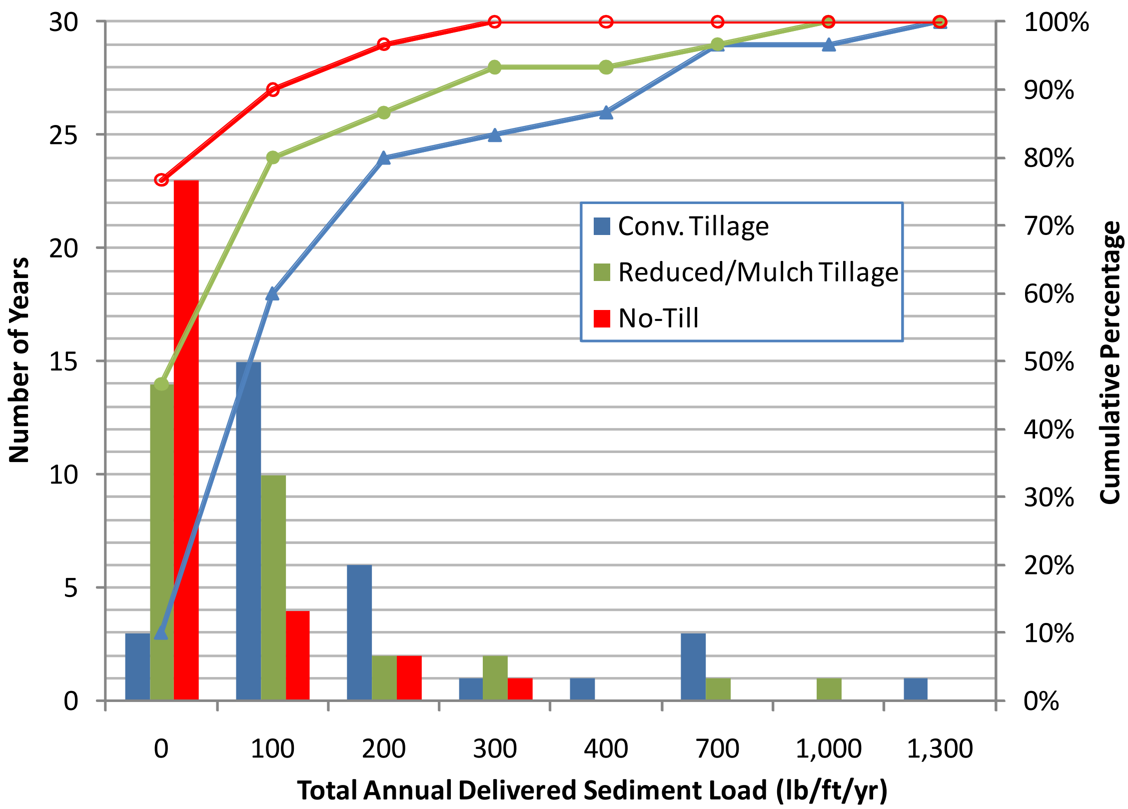

Figure 32. The effect of tillage practice on annual sediment load in the high precipitation zone for a 30 year simulation using the WEPP model. Lines indicate cumulative percent sediment load for all 30 years of the simulation.

<u>Identification of Source Areas:</u>

One common observation in watershed studies is that the majority of the sediment comes from a few source areas. In this section we quantify the importance of source areas relative to overall sediment load for each of the agriculturally dominated watersheds in the Lower Snake River basin using the erosion simulation by the RUSLE approach.

The 30-meter spatial resolution erosion maps predicted using RUSLE approach, described elsewhere in the report, were reclassified into two classes based on predicted erosion rates. The portion of the overall soil erosion for the entire watershed coming from each class was then quantified and presented in Figure 33 and Figure 34. These two figures show the proportion of overall erosion in each watershed derived from areas having erosion rates exceeding 5 t/ac and 10 t/ac, respectively. As seen in Figure 33 nearly 60% of the overall erosion in the Clearwater basin is derived from slightly more than 30% of the watershed area. Similarly nearly 16% of the overall erosion in the Clearwater watershed is derived from less than 5% of the watershed area. This trend is consistent among all the agriculturally dominant watersheds in the Lower Snake River basin.

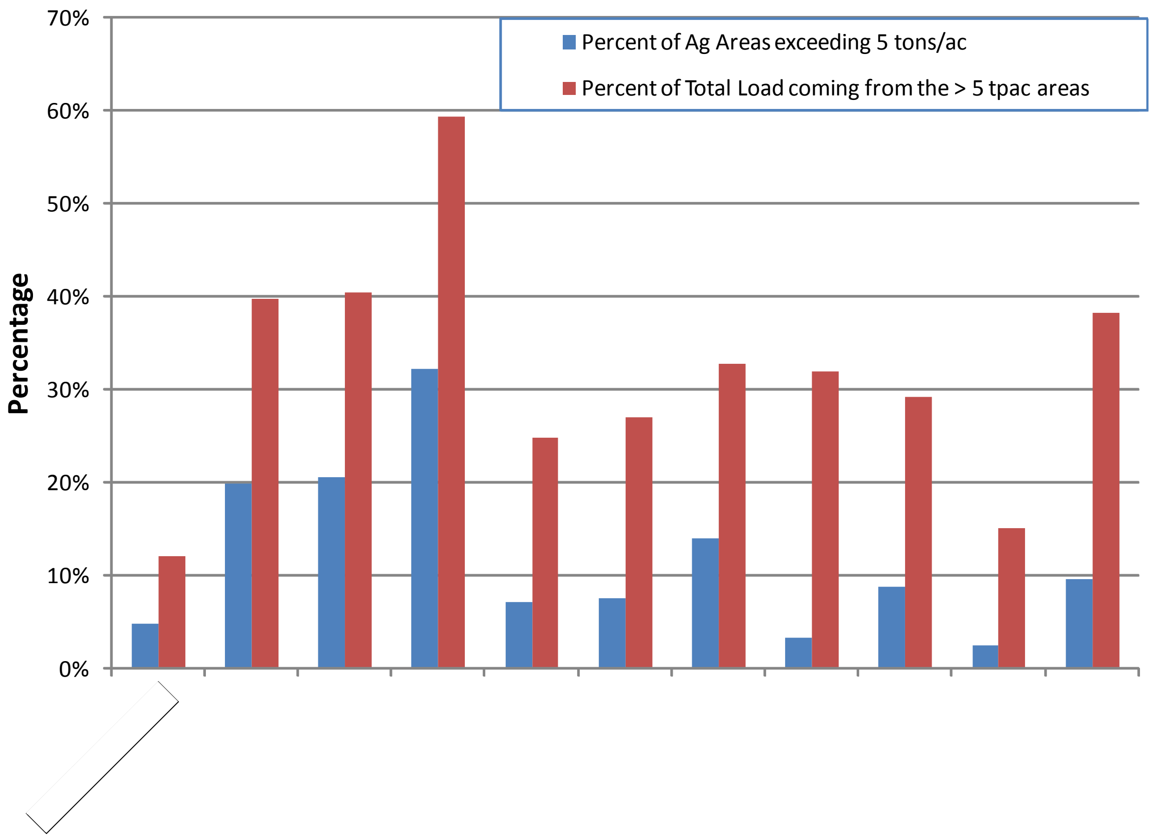

Figure 33. The proportion of the overall sediment load for specific watersheds coming from areas having erosion rates exceeding 5 t/ac as simulated using the RUSLE approach.

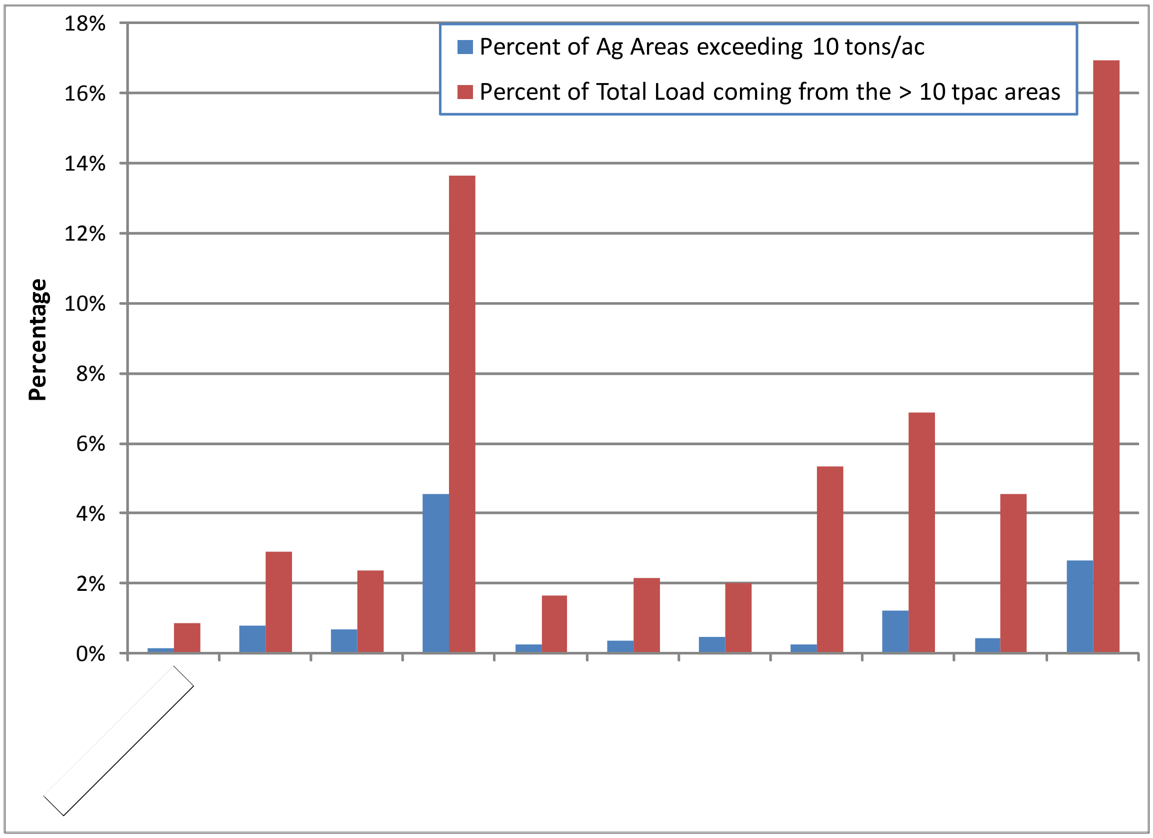

Figure 34. The proportion of the overall sediment load for specific watersheds coming from areas having erosion rates exceeding 10 t/ac as simulated using the RUSLE approach.

Importance of Conservation Reserve Program:

As seen in the following section the majority of sediment often is derived from a relatively small portion of the overall watershed. The primary implication of this is that management practices which focus on the highly erosive areas of a watershed will likely provide the greatest reduction in sediment load per dollar invested. This conceptual idea has been the primary motivation behind the Conservation Reserve Program which provides land owners with annual payments to establish and maintain perennial grass cover for a minimum of 10 years on highly erodible land. This program, which was started in the mid 1980s, has been widely adopted throughout the Lower Snake River Basins. With the exception of Whitman County, WA, the number of acres enrolled in the CRP program has gradually increased since 1986, see Figure 35. Interestingly there was a substantial increase in the number of acres enrolled in CRP in Whitman County from 1999 to 2007. As of 2007, the proportion of the total agricultural land enrolled in the CRP ranges from near 5% in Lewis and Nez Perce counties in Idaho to as high as 37% in Asotin County, WA, see Figure 36. Despite the substantial increase in number of acres enrolled in the CRP from 1999 to 2007 in Whitman County, the relative proportion of CRP ground to total agricultural farmland is relatively small, less than 20%, compared to many of the counties in the Lower Snake River basin.

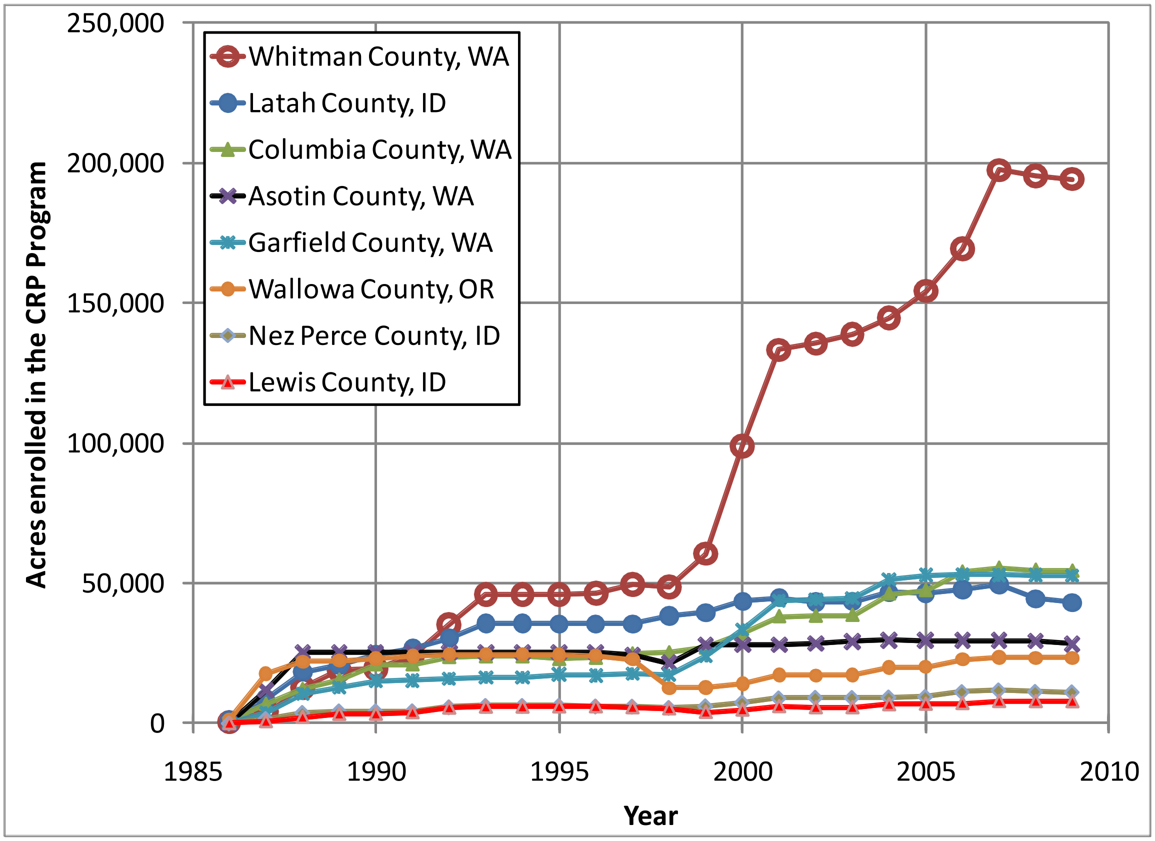

Figure 35. Number of acres enrolled in the Conservation Reserve Program (CRP) per year since 1986 by county in Washington, Oregon, and Idaho.

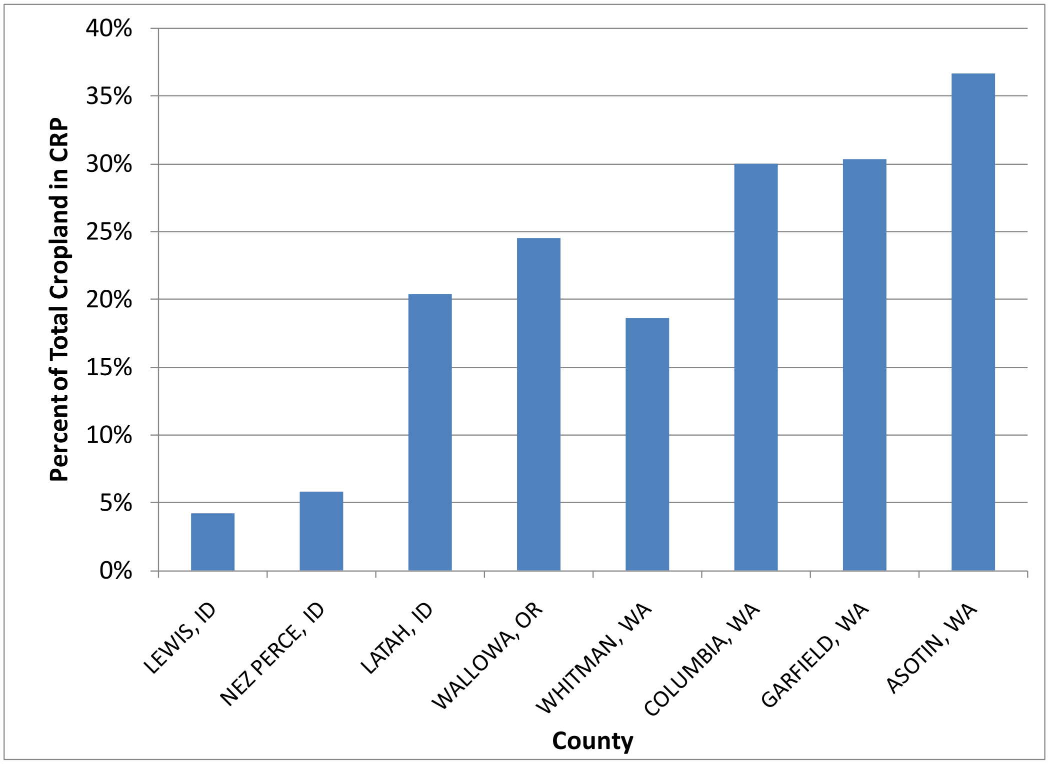

Figure 36. Percent of the total cropland area enrolled in the Conservation Reserve Program (CRP) in 2007 by county in Washington, Oregon, and Idaho.

As a government program to pay landowners to preserve land rather than produce a product, the benefits of the CRP is often closely scrutinized and debated in the public and political sectors. However as seen in this erosion modeling exercise, the long term consequences of elimination of CRP on sediment loading could be devastating to the ecosystems in the basin. As seen in Figure 36, on average 20% of all agricultural cropland in the Lower Snake River basin is enrolled in CRP program. Assuming the CRP ground was successfully applied to the most erodible fields in a watershed, then the transition of this land back to active cropland could greatly increase the overall erosion rates in the watershed. According to Figure 33 using the RUSLE approach, the most erodible 20% of land in the Palouse and Tucannon watershed contribute 40% of the overall sediment load. This implies that the conversion of CRP back to cropland could potentially double the amount of delivered sediment in each watershed. Although it is unlikely that all CRP ground has been adopted in the most erosive areas, or that all CRP ground will be converted back to cropland, the increase in sediment load is likely to be very significant if the CRP program were to be eliminated. As seen in Table 13 and Table 14, if the CRP program were to be eliminated or scaled back then this analysis would highly recommend that operators follow reduced or no-till farming practices on this highly erosive ground to minimize the increase in sediment load. Adding buffers and gully plugs to most highly erosive areas should also be encouraged.

Beneficial Sediment Characteristics:

Finally, it should be pointed out that any effort to reduce sediment downstream should be evaluated in context of the potential impacts to tributary streams in the area. Lane et al. (1996) demonstrated that the timing of flow and sediment supply processes is critical in determining the nature of morphological changes in both the short and long-term at the local level. Several of the streams in the study area are already sediment starved with respect to certain grain size categories. Avoiding unintended consequences of watershed-scale restoration would require adopting a comprehensive framework such as the one proposed by Shields et al. (2003).

4.0 Summary and Recommendations

In spite of significant reductions in agricultural sediment yields over the past couple of decades because of BMP adoption, there are still areas where large quantities of fine grain sediments reach tributary stream channels. Adoption of agricultural BMPs such as no-till (or reduced tillage), grassed buffer strips, cattle fencing, and riparian corridors appear to be reasonably effective at reducing sediment loads. However, while there are important ecological and sustainability reasons that efforts to expand agricultural BMPs should continue (Montgomery 2007), the impacts on US Army Corps of Engineers dredging frequency near the confluence of the Snake and Clearwater Rivers would likely be quite small. The grain size fractions found in the USGS core data from the confluence area are considerably larger than most of the agricultural soils. Furthermore, results of the WEPP modeling included in this report indicate very little of the sand sized particles reach the stream.

According to the erosion modeling conducted in this report, the highest priority for minimizing erosion in the Lower Snake River basin should be focused on adoption of reduced tillage practices. Drive-by surveys indicate many farmers still follow traditional conventional tillage practices which leave little surface residue cover and have the greatest risk of erosion. The RUSLE2, the GIS-based RUSLE approach, and the WEPP model all indicate that the highest erosion rates occur in the high precipitation zone in areas where operators still follow conventional tillage practices. Both buffer strips and gully plugs are effective at minimizing the erosion and sediment yield however, since both these practices take land out of production and require annual maintenance, these practices would likely require financial incentives to encourage widespread adoption. Adoption of no-till should be highly encouraged however more research and outreach is likely necessary to dispel owner and operator concerns over potential risks of this technique. Since the majority of the sediment load in many of the watersheds in the Lower Snake River basin is derived from a relatively small fraction of the total watershed area conservation reserve program (CRP) has likely been a significant factor in the reduction of sediment load observed over the last 25 years. Elimination of the CRP program could potentially double the amount of sediment load delivered by the agriculturally dominated watersheds in the lower Snake River Basin.

With respect to controlling streambank and stream channel scour, there is simply not enough long-term data to develop accurate assessment with existing modeling tools. We observed a few obvious down-cutting situations and a few streambank scour reaches during our field assessment and the literature generally supports the conclusion that changes in land use typically leads to increases in bank-full flows that produces additional stream bed aggradation. It is difficult, however, to quantify the overall impact on sediment deposition in Lower Granite Pool due in part because of insufficient data sets. Furthermore, after a thorough examination of the causes of these types of erosion, it is unclear what steps the USACE could take with respect to significantly modifying the hydrographs. Some of the streambank erosion occurred within established riparian zones so simply laying cause-effect on poor riparian conditions does not seem appropriate. After all, large woody debris recruitment in some watersheds requires some periodic undercutting of tree/root systems. Finally, while models such as CONCEPTS, WEPP, and CCHE2D represent state-of-the-art constructs, none of the models produces uncalibrated results with enough confidence to site restoration projects. The sensitivity of these solutions was shown using critical bed shear calculations.

It is also important to note that elimination of all sediment is generally not a desired course of action. Schmidt et al. (2007) found that the area of sand bars exposed at low discharge in Hells Canyon has decreased 50 percent since dam closure at the Hells Canyon Complex. The adverse impacts of Hells Canyon Dam on the downstream riparian ecosystem were investigated and summarized by Braatne et al. (2008). Therefore, it is important to recognize that sediment is in part a natural process so eliminating all sediment should not be a goal.

References

Aksoy, H. and Kavvas, M.L. 2005. A review of hillslope and watershed scale erosion and sediment transport models. Catena. Vol. 64, No. 2-3, pp 247-271.

Alonso, C.V. and Combs, T.S. 1990. Streambank erosion due to bed degradation: a model concept. Transactions of the ASABE. Vol. 33, No. 4, pp 1239-1248.

Beaumont, C., Fullsack, P. and Hamilton, J. 1992. Erosional control of active compressional orogens. In Thrust Tectonics, edited by K. R. McClay, pp. 1–18, Chapman and Hall, New York.

Beck, M.B. 1987. Water quality modeling: a review of uncertainty. Water Resources Research. Vol. 23, No. 8, pp 1393–1442.

Boll, J., Brooks, E.S. and Traeumer, D. 2001. Hydrologic and sediment delivery analysis of agriculturally dominated watersheds in the Clearwater River basin. Final report to Idaho Soil Conservation Commission, Moscow, ID.

Braatne, J.H., Rood, S.B., Goater, L.A., and Blair, C.L. 2008. Analyzing the impacts of dams on riparian ecosystems: a review of research strategies and their relevance to the Snake River through Hells Canyon. Environmental Management. Vol. 41, No. 2, pp 267-281.

Brooks, E.S., J. Boll, A. Snyder, K.M. Ostrowski, S.L. Kane, J.D. Wulfhorst, L.W. Van Tassell, and R. Mahler. 2010. Long term sediment loading trends in the Paradise Creek Watershed. Journal of Soil and Water Conservation, 65:6-331-341, doi:10.2489/jswc.65.6.331.

Brune, G.M. 1951. Collection of basic data on sedimentation. Proceedings of the Conference on Water Resources, Illinois State Water Survey, Urbana, IL.

Bull, L.J. and Kirkby, M.J. 1997. Gully processes and modelling. Progress in Physical Geography. Vol. 21, No. 3, pp 354–374.

Clark, L.A. and Wynn, T.M. 2007. Methods for determining streambank critical shear stress and soil erodibility: implications for erosion rate predictions. Transactions of the ASABE. Vol. 50, No. 1, pp 95-106.

Crowder, B.M. 1987. Economic costs of reservoir sedimentation: a regional approach to estimating cropland erosion damage. Journal of Soil and Water Conservation, Vol. 42, No. 3, pp 194-197.

Dechert, T. 2004. Draft sediment calculations for Potlatch basin, Personal communication, Idaho Department of Environmental Quality, Lewiston, ID.

Downer, C.W. and Ogden, F.L. 2002. GSSHA user's manual, gridded surface subsurface hydrologic analysis version 1.43 for WMS 6.1. ERDC Technical Report, Engineering Research and Development Center, Vicksburg, MS.

Duan, J.G. 2005. Analytical approach to calculate rate of bank erosion. ASCE Journal of Hydraulic Engineering. Vol. 131, No. 11, pp 980-990.

Duan, J.G., Wang, S.S.Y. and Jia, Y. 2001. The applications of the enhanced CCHE2D model to study the alluvial channel migration processes. Journal of Hydraulic Research, Vol. 39, No. 5, pp 469-480.

Dunbar, J.A., Allen, P.M. and Higley, P.D. 1999. Multifrequency acoustic profiling for water reservoir sedimentation studies. Journal of Sedimentary Research, Vol. 69, No. 2, pp 518-527.

Eakin, H.M. and Brown, C.A. 1939. Siltation of reservoirs. Technical bulletin (United States. Dept. of Agriculture) No. 524, p 168.

Ebbert, J.C. and Roe, R.D. 1998. Soil erosion in the Palouse River Basin: Indications of improvement: U.S. Geological Survey Fact Sheet FS-069-98, on line at URL http://wa.water.usgs.gov/pubs/fs/fs069-98/, accessed 6/30/2009.

Enters, T. 1998. Methods for the economic assessment of the on- and off-site impacts of soil erosion. International Board for Soil Research and Management. Issues in Sustainable Land Management No. 2. Bangkok: IBSRAM.

Fan, J. and Morris, G.L. 1992. Reservoir sedimentation. I: delta and density current deposits. Journal of Hydraulic Engineering, Vol. 118, No. 3, pp. 354-369.

Fernandez, C., Wu, J.Q., McCool, D.K., and Stockle, C.O. 2003. Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. Journal of Soil and Water Conservation, Vol. 58, pp 128–136.

Flores-Cervantes, J.H., Istanbulluoglu, E. and Bras, R.L. 2006. Development of gullies on the landscape: a model of headcut retreat resulting from plunge pool erosion. Journal of Geophysical Research. Vol. 111, doi:10.1029/2004JF000226.

Garbrecht, J., Kuhnle, R. and Alonso, C. 1995. A sediment transport capacity formulation for application to large channel networks. Journal of Soil and Water Conservation, Vol. 50, No. 5, pp 527-529.

Haan, C.T., Barfield, B.J., and Hayes, J.C. 1994. Design hydrology and sedimentology for small catchments. Academic Press, Harcourt Brace & Company, San Diego, CA.

Hansen, L. and Hellerstein, D. 2007. The value of the reservoir services gained with soil conservation. Land Economics, Vol. 83, No. 3, pp 285-301.

Hessel, R. Jetten, V., Liu, B., Zhang, Y. and Stolte, J. 2003. Calibration of the LISEM model for a small Loess Plateau catchment. Catena, Vol. 54, No. 1-2, pp 235-254.

Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N. McKerrow, A., Van Driel, J.N., and Wickham, J. 2007. Completion of the 2001 National Land Cover database for the conterminous United States. Photogrammetric Engineering and Remote Sensing, Vol. 73, No. 4, pp 337-341.

Hooke, J.M. 1979. An analysis of the processes of river bank erosion. Journal of Hydrology, Vol. 42, Issue 1-2, pp 39-62.

Howard, A.D., Dietrich, W.E., and Seidl, M.A. 1994. Modeling fluvial erosion on regional to continental scales. Journal of Geophysical Research, Vol. 99, No. B7, pp 13971-13986.

Howard, A. D. and Kerby, G. 1983. Channel changes in badlands, Geologic Society of America Bulletin, Vol. 94, pp 739–752.

Idaho Department of Environmental Quality (IDEQ). 2003. South Fork Clearwater River Subbasin Assessment and Total Maximum Daily Loads. Prepared by Dechert, T. and Woodruff L., Idaho Dept. of Environmental Quality 276 pp.

Julian, J.P. and Torres, R. 2005. Hydraulic erosion of cohesive riverbanks. Geomorphology. Vol. 76, No. 1-2, pp 193-206.

Kalin, L. and Hantush, M.M. 2003. Evaluation of sediment transport models and comparative application of two watershed models. EPA/600/R-03/139. USEPA Office of Research and Development. Cincinnati, OH.

Kim, S-C, Friedrichs, C.T., Maa, JP-Y, Wright, L.D. 2000. Estimating bottom stress in tidal boundary layer from Acoustic Doppler velocimeter data. Journal of Hydraulic Engineering, ASCE, Vol. 126, No. 6, pp 399–406.

Kinnell, P. and Risse, L. 1998. USLE-M: Empirical modeling rainfall erosion through runoff and sediment concentration. Soil Science Society Am Journal. Vol. 62, No. 6, pp 1667–1672.

Kok, H., Papendick, R.I., and Saxton, K.E.. 2009. STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands. Journal of Soil and Water Conservation, July/August 2009, Vol. 64, No. 4, pp 253-264.

Laflen, J.M., Lane, L.J., and Foster, G.R. 1991. WEPP: A new generation of erosion prediction technology. Journal of Soil and Water Conservation. Vol. 46, pp 34–38.

Lane, S.N., Richards, K.S. and Chandler, J.H. 1996. Discharge and sediment supply controls on erosion and deposition in a dynamic alluvial channel. Geomorphology, Vol. 15, Issue 1, pp 1-15.

Langendoen, E.J. and Simon, A. 2008. Modeling the evolution of incised streams. II: streambank erosion. ASCE Journal of Hydraulic Engineering, Vol. 134, No. 7, pp 905-915.

Lee, L.K. 1984. Land use and soil loss: a 1982 update. Journal of Soil and Water Conservation, Vol. 39, pp 226-228.

Loch, R. and Rosewell, C. 1992. Laboratory methods for measurement of soil erodibilities (K factors) for the universal soil loss equation. Australian Journal of Soil Research. Vol. 30, pp 233–248.

McCool, D.K., Foster, G.R., and Weesies, G.A. 1993. Slope Length and Steepness Factor. In "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)", Chapter 4, USDA-ARS Special Publications.

McCool, D.K. and Roe, R.D. 2005. Long-term erosion trends on cropland in the Pacific Northwest. Presented at the 2005 Pacific Northwest Section Meeting of the ASAE, Lethbridge, Alberta, Canada, Sept. 22-24, 2005. ASAE Section Meeting Paper No. PNW05-1002. St. Joseph, Mich., pp. 17.

McCool, D.K., Personal communication June, 2001.

Merritt, W.S., Letcher, R.A., and Jakeman, A.J. 2003. A review of erosion and sediment transport models. Environmental Modelling & Software, Vol. 18, pp 761-799.

Mitasova, H., Hofierka, J., Zlocha, M., and Iverson, L.R. 1996. Modelling topographic potential for erosion and deposition using GIS. International Journal of Geographical Information Systems. 10(5): 629-641.

Moltz, H.L.N., Lopes, V.L., Rast, W., and Ventrua, S.J. 2010. Hydrologic-Economic Analysis of Best Management Practices for Sediment Control in the Santa Fe Watershed, New Mexico. ASCE Journal of Hydrologic Engineering, Vol. 15, No. 4, pp 308-317.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences of the United States of America. Vol. 104, No. 33, pp 13268-13272.

Morris, G.L. and Fan, J. 1998. Reservoir sedimentation handbook: design and management of dams, reservoirs, and watersheds for sustainable development. McGraw-Hill, New York, NY.

Murgatroyd, A.L. and Ternan, J.L. 2006. The impact of afforestation on stream bank erosion and channel form. Earth Surface Processes and Landforms, Vol. 8, No. 4, pp 357-369.

Nyssen, J., Poesen, J., Veyret-Picot, M., Moeyersons, J., Haile, M., Deckers J., Dewit, J., Naudts, J., Teka, K., and Govers, G. 2006. Assessment of gully erosion rates through interviews and measurements: a case study from northern Ethiopia. Earth Surface Processes and Landforms, Vol. 31, pp. 167–185.

Pacific Southwest Inter-agency Committee (PSIAC), Water Management Subcommittee. 1968. Factors affecting sediment yield in the Pacific Southwest area and selection and evaluation of measures for reduction of erosion and sediment yield.

Palmieri, A., Shah, F., and Dinar, A. 2001. Economics of reservoir sedimentation and sustainable management of dams. Journal of Environmental Management, Vol. 71, No. 2, pp 149-163.

Parsons, J.E., Thomas, D.L., Huffman, R.L. (Eds.), 2001. Non-point source water quality models: Their use and application. Final Report of USDA-CSREES Southern Region Research Project S-273, Development and Application of Comprehensive Agricultural Ecosystems Models, 200 pp.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., and Blair, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science, Vol. 267, No. 5201, pp 1117–1123.

Proffit, G.T., and Sutherland, A.J. 1983. Transport of nonuniform sediment. Journal of Hydraulic Research, Vol. 21, No. 1, pp 33–43.

Prosser, I.P. and Rustomji, P. 2000. Sediment transport capacity relations for overland flow. Progress in Physical Geography. Vol. 24, No. 2, pp. 179–193.

Poesen, J., Nachtergaele, J., Verstraeten, G., and Valentin, C. 2003. Gully erosion and environmental change: importance and research needs. Catena., Vol. 50, pp 91–133.

Queensland Government. 2009. What causes streambed erosion? Department of Environment and Resource Management. http://www.derm.qld.gov.au/factsheets/pdf/river/r20.pdf.

Quigley, T.M., and Arbelbide,, S.J. Editors. 1997. An Assessment of Ecosystem Components in the Interior Columbia Basin and Portions of the Klamath and Great Basins, Volumes I-IV. USDA Forest Service, Pacific Northwest Research Station and USDI Bureau of Land Management. General Technical Report PNW-GTR-405.

Randle, T.J., Yang, C.T., and Daraio, J. 2006. Erosion and reservoir sedimentation (Chapter 2). Sedimentation and River Hydraulics Group, US Bureau of Reclamation, Denver, CO. http://www.usbr.gov/pmts/sediment/kb/ErosionAndSedimentation/chapters/Chapter2.pdf

Rashid, S.M.H. 2010. Effectiveness of widely used critical velocity and bed shear stress equations for different types of sediment beds. Masters of Science in Civil Engineering, Washington State University, Pullman, WA.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C. (coordinators). 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation. U.S. Department of Agriculture, Agriculture Handbook No. 703. 404 pp.

Roehl, J.W. 1962. Sediment source areas, delivery ratios, and influencing morphological factors. Symposium on Land Erosion, International Association of Scientific Hydrology. October. http://iahs.info/redbooks/a059/059023.pdf.

Rose, C.W. 1993. Erosion and sedimentation. In: Bonell, M., Hufschmidt, M.M., Gladwell, J.S. (Eds.), Hydrology and Water Management in the Humid Tropics: Hydrological Research Issues and Strategies for Water Management. Cambridge University Press, pp. 301–343.

Schmidt, J.C., Grams, P.E., and Webb, R.H. 2007. Comparison of the magnitude of erosion along two large regulated rivers. Journal of the American Water Resources Association. DOI: 10.1111/j.1752-1688.1995.tb03389.x

Shields, F.D., Copeland, R.R., Klingeman, P.C., Doyle, M.W., and Simon, A. 2003. Design for stream restoration. ASCE Journal of Hydraulic Engineering, Vol. 129, No. 8, pp. 575-584.

Slingerland, R., Willett, S.D. and Hennessey, H.L. 1997. A new fluvial bedrock erosion model based on the work-energy principle, Eos Trans. AGU, 78(46), Fall Meet. Suppl., F299.

Smith, R.E., Goodrich, D.C., and Quinton, J.N. 1995. Dynamic, distribution simulation of watershed erosion: the KINEROS2 and EUROSEM models. Journal of Soil and Water Conservation, Vol. 50, No. 5, pp 517-520.

Smith, R.D., Sidle, R.C., and Porter, P.E. 2006. Effects on bedload transport of experimental removal of woody debris from a forest gravel-bed stream. Earth Surface Processes and Landforms, Vol. 18, No 5, pp 455-468.

Strand, R.I. 1975. Bureau of Reclamation procedures for predicting sediment yield. In Present and Prospective Technology for Predicting Sediment Yields and Sources, Proceedings of the Sediment-Yield Workshop, USDA Sedimentation Laboratory, Oxford, Mississippi, November 28-30, 1972.

Strand, R.I. and Pemberton, E.L. 1982. Reservoir sedimentation technical guidelines for Bureau of Reclamation. U.S. Bureau of Reclamation, Denver, CO.

Teasdale, G.N. and Barber, M.E. 2008. Aerial Assessment of Ephemeral Gully Erosion from Agricultural Regions in the Pacific Northwest. Journal of Irrigation and Drainage Engineering, American Society of Civil Engineers. Vol. 134, No. 6, pp 807-814.

Tebebu, T.Y., Abiy, A.Z., Zegeye, A.D., Dahlke, H.E., Easton, Z.M., Tilahun, S.A., Collick, A.S., Kidnau, S., Moges, S., Dadgari, F. and Steenhuis, T.S. 2010. Surface and subsurface flow effect on permanent gully formation and upland erosion near Lake Tana in the northern highlands of Ethiopia. Hydrology and Earth System Sciences, Vol. 14, pp 2207-2217.

TetraTech. 2006. Investigation of sediment sources and yield, management and restoration opportunities with the Lower Snake River Basin. Contract W912EF-05-D-0002, USACE, Walla Walla, WA.

Trimble, S.W. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science, Vol. 278, No. 5342, pp 1442-1444.

Trimble, S.W. and P. Crosson, 2000. U.S. soil erosion rates—myth and reality. Science, Vol. 289, No. 5477, pp 248-250.

Tucker, G.E. and Whipple, K.X. 2002. Topographic outcomes predicted by stream erosion models: sensitivity analysis and intermodel comparison. Journal of Geophysical Research, Vol. 107, No. B9, 2179, doi:10.1029/2001JB000162.

US Bureau of Reclamation (USBR). 2006. Erosion and Sedimentation Manual. Department of Interior, Sedimentation and River Hydraulics Group, Denver, CO. http://www.usbr.gov/pmts/sediment/kb/ErosionAndSedimentation/Contents.pdf

Vanoni, V.A. 1975. Sedimentation Engineering, American Society of Civil Engineers. 745p.

Vanoni, V.A. 2006. Sedimentation Engineering. ASCE Task Committee for the Preparation of the Manual on Sedimentation, Engineering Practice Report No. 54, Reston, VA.

Vente, J., J. Poesen, M. Arabkhedri, and G. Verstraeten, 2007. The sediment delivery problem revisited. Progress in Physical Geography, Vol. 31, No. 2, pp 155-178.

Vogelmann, J.E., Howard, S.M. Yang, L., Larson, C.R., Wylie, B.K. and VanDriel, J.N. 2001. Completion of the 1990's National Land Cover data set for the conterminous United States. Photogrammetric Engineering and Remote Sensing, Vol. 67, pp. 650-662.

Wheater, H.S., Jakeman, A.J., Beven, K.J., 1993. Progress and directions in rainfall-runoff modelling. In: Jakeman, A.J., Beck, M.B., McAleer, M.J. (Eds.), Modelling Change in Environmental Systems. John Wiley and Sons, Chichester, pp. 101–132.

Whipple, K.X., and Tucker, G.E. 1999. Dynamics of the stream power river incision model: Implications for height limits of mountain ranges, landscape response timescales and research needs, J. Geophys. Res., 104, pp 17,661– 17,674.

Wicks, J.M. and Bathurst, J.C. 1996. SHESED: a physically based, distributed erosion and sediment yield component for the SHE hydrological modelling system. Journal of Hydrology, Vol. 175, Issue 1-4, pp 213-238.

Wolman, M.G. 1959. Factors influencing erosion of a cohesive riverbank. American Journal of Science. 257: 204-216.

Wu, W. and Vieira, D.A. 2002. One-dimensional channel network model CCHE1D 3.0-Technical manual. Technical Rep. No. NCCHE-TR-2002-1, National Center for Computational Hydroscience and Engineering, University of Mississippi, University, Miss.

Wu, W. Wang, S.S.Y. and Jia, Y. 2000. Nonuniform sediemtn transport in alluvial rivers. Journal of Hydraulic Research, IAHR. Vol. 38, No. 6, pp 427-434.